



## Microclimate, Air Quality, Physiological Responses, and Production Performance of Broilers Raised in a Closed Housing System with Plastic Slatted Flooring

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**Article History:** 25-240    Received: 26-Aug-25    Revised: 13-Nov-25    Accepted: 23-Nov-25    Online First: 06-Dec-25

### ABSTRACT

The use of rice husks as floor mats in broiler chickens rearing in closed house systems faces sustainability challenges related to availability, inconsistent quality and their role as a source of particulate pollution in the air. This study aimed to comprehensively evaluate the potential of plastic slat flooring as a substitute for traditional rice husk mats. A comparative study was conducted at a commercial Teaching Farm Closed House PT Hasanuddin Agrivisi Internusa in Makassar, Indonesia. This research compares two treatments in a closed house with a capacity of 25,000 chickens per cage: rice husk litter floor mats and plastic slat floors. The key parameters measured included microclimate conditions, air quality, physiological responses, and broiler production performance. The results showed a significant improvement in air quality ( $P < 0.05$ ) in the slatted flooring cage, evidenced by a much lower concentration of particulate matter (PM) $<100\mu\text{m}$  ( $304.30 \pm 59.65 \mu\text{g}/\text{Nm}^3$ ) compared to litter ( $618 \pm 21.55 \mu\text{g}/\text{Nm}^3$ ). Furthermore, broilers reared on slatted flooring showed significantly higher weight gain ( $P < 0.05$ ) ( $1,632 \pm 35.58 \text{g}$ ) than those reared on litter flooring ( $1,572 \pm 49.86 \text{g}$ ). In conclusion, the use of plastic slat flooring not only improves air quality by reducing particulate pollution but also improves the growth performance of broilers.

**Keywords:** Broiler chickens, Closed-house, Air quality, Plastic slat flooring, Performance, Rice husks.

### INTRODUCTION

Located in a tropical and archipelagic region, Indonesia faces challenges in broiler chicken farming. According to the Meteorology, Climatology and Geophysics Agency of the Republic of Indonesia (BMKG 2022) data, Indonesia's climate conditions range from 23°C to 35°C in temperature and 40% to 99% in humidity, with the rainy season occurring from October to March and the dry season from April to September. These climatic conditions do not match the comfort zone of broiler chickens, which is a temperature of 18-24°C (for chickens older than 14 days) with 50-70% humidity (Oke et al. 2020). High temperatures disrupt the physiological state of chickens, resulting in several negative effects, such as changes in hormonal balance and decreased productivity. Heat stress is detrimental to the growth performance, gut health, and immune function of poultry, all of which are critical for maintaining productivity (Liu et al. 2020; Ahmad et al. 2022).

An intensive poultry rearing system produces higher performance (Lase et al. 2024). A rearing system using a closed house has been shown to reduce the impact of these climatic conditions. The use of a closed house system effectively controls the barn microclimate, resulting in improved poultry health, productivity, and welfare (Ornelas-Eusebio et al. 2020; Shahzad et al. 2021). A rearing system using a closed house requires various supporting components to ensure the successful production of broilers. Litter is an essential component that must be adequately provided in terms of quantity and quality as bedding material for the coop.

In Indonesia, rice husks, an agricultural waste, are widely used as litter flooring in closed houses. However, with the increasing number of closed houses, the need for rice husks has increased. In other industries, rice husks have also begun to be used as a biomass raw material, such as for the gasification of power plants (Hoque et al. 2021; Nyakuma et al. 2021), production of silica and nanoparticles (Rodriguez-Otero et al. 2023).

**Cite This Article as:** Daryatmo, Ulupi N, Afnan R, Yani A and Ali HM, 2025. Microclimate, air quality, physiological responses, and production performance of broilers raised in a closed housing system with plastic slatted flooring. *International Journal of Veterinary Science* 15(2): 362-368. <https://doi.org/10.47278/journal.ijvs/2025.152>

Therefore, competition for obtaining rice husks is increasing, which will affect their availability and price. According to the Central Statistics Agency of the Republic of Indonesia (BPS 2025), there was a reduction in the area of rice fields in 2024, amounting to 167.67 thousand hectares compared to 2023. Therefore, the production of rice husk waste has certainly decreased, and some regions have had to bring rice husks from other regions, which has increased transportation costs.

The quality of rice husks as litter is also influenced by high rainfall and humidity during the rainy season. Moist husks can serve as a medium for disease transmission, as they create an environment that supports the growth of pathogenic microorganisms such as Enterobacteriaceae and Enterococcaceae (Gupta et al. 2021). In addition, husks can become a breeding ground for *E. coli*, which has been identified as a causative agent of colibacillosis (Shtylla et al. 2023). Decreased air quality, both inside and outside the cage, is associated with increased levels of ammonia, carbon dioxide, and dust (Brink et al. 2022). In addition to litter management, farmers often face challenges such as the accumulation of clumped and wet husks, which can lead to increased concentrations of dust and ammonia. These pollutants pose a significant risk to poultry health by causing respiratory distress and in severe cases, death, and environmental conditions that contribute to the production of acid rain and nitrogen (N) deposition in the ecosystem (Anderson et al. 2021; Corrêa-Junior et al. 2024).

Currently, plastic slat flooring has been introduced to replace rice husks in broiler chicken rearing systems in closed houses. Several studies on the use of plastic slat flooring have shown its potential as a substitute for litter flooring. The use of plastic slats results in higher live weight and carcass weight, as well as better air quality (Almeida et al. 2017; Almeida et al. 2018). The use of plastic slats in poultry housing can enhance air circulation and minimize direct contact between chickens and feces, thereby mitigating ammonia emissions and reducing dust levels in closed houses (Ogino et al. 2021). In addition, the production of heat from the floor was lower owing to air movement, which helped reduce heat buildup on the floor. This is important for maintaining an optimal environment to support broiler growth (Ferreira et al. 2024). However, comprehensive information on the use of plastic slats in commercial closed houses is still limited. This study aimed to evaluate the use of plastic slats as a substitute for rice husks in closed houses on an industrial scale, in terms of microclimatic conditions, air quality, physiological response, and production performance.

## MATERIALS AND METHODS

### Ethical approval

All materials, equipment, and procedures used in this study were approved by the Animal Ethics Committee of the School of Veterinary Medicine and Biomedical Sciences, Bogor Agricultural University (approval number 332/KEH/SKE/V/2025).

### Study area

This study was conducted at the Teaching Farm Closed House of PT. Hasanuddin Agrivisi Internusa Makassar. Air quality testing was performed at the Air Pollution and Noise Laboratory of the Department of Environmental

Engineering, Hasanuddin University. White blood cell analysis was performed at the Laboratory of Animal Physiology of Hasanuddin University, Makassar City, South Sulawesi Province, Indonesia.

### Equipment and materials

The equipment used in this study was a closed house with a tunnel ventilation system with litter and plastic slat flooring. The size of each cage was 120m long and 12m wide, with a capacity of 25,000 chicks. The research cage was equipped with a pan feeding, drinking, heating, and automatic ventilation system. The test equipment used for each parameter is described in the research procedures.

The materials used in this study were day-old chick (DOC) Cobb strain 50,000 with an average weight of 50.1±5.3g per head, rice husks, drinking water, vitamins, vaccines, disinfectants, and commercial feed in the pre-starter, starter, and finisher phases. The nutritional content of broiler feed met the required standards, with a crude protein content of 19-21%, metabolizable energy of 3000-3200 kcal/kg, and a maximum crude fiber content of 6% (Cobb 2021).

### Research protocol

Broiler chickens were raised using industry-scale management and were maintained for 4 weeks (28 days). The chickens were maintained in two closed house units, each with a capacity of 25,000 birds. The litter flooring-type cage used rice husks with a thickness of 10cm, and the slat-type cage used a plastic slat with a hole gap of 1×1cm and a height from the floor of 20cm. Each cage was equipped with a fan feeder, nipple, heating system, and automatic ventilation system. In this study, the brooding period was two weeks long. Each cage consisted of four plots with partitions, each measuring 12×30m, and each plot contained 6250 chickens. Before the DOC was maintained, each cage was sprayed with disinfectant and fumigated. The DOC used in this study was vaccinated at the hatchery. Broiler chickens were provided ad libitum access to feed and drinking water throughout the experiment.

### Parameter studied

#### Microclimate

The microclimates of the cages were observed in a closed house. Microclimate observations included temperature and humidity measurements, wind speed, and the temperature humidity velocity index (THVI).

#### The temperature and humidity

The temperature and humidity of the air in the cage were measured using a thermohygrometer data logger installed in four parts of each cage at a height of 40cm from the cage floor. The Hobo data logger was set to record the temperature and humidity data every 10 minutes.

#### Wind speed

It was measured using a Kestrel anemometer. Kestrel is placed in the middle of the cage with a height of 40cm, with m/s units taken every day at 07.00 am, 12.00 pm, and 05.00 pm.

#### Temperature humidity velocity index (THVI)

It was calculated using the formula: Tao and Xin (2003)  

$$THVI = (0.85 \times T_{db} + 0.15 \times T_{wb}) \times V^{-0.058} \quad (1)$$

Information:

Tdb = Dry ball temperature (°C)

Twb = Wet ball temperature (°C)

V = Air velocity (m/s)

### Air quality

Air quality testing was conducted in a closed house. Data collection in the cage for each period was carried out in the 4th week at three points in the cage. Air quality testing includes oxygen (O<sub>2</sub>), ammonia (NH<sub>3</sub>) (SNI 2005), carbon dioxide (CO<sub>2</sub>), and particulate matter (PM)<100µm (SNI 2004).

### Physiological responses

Physiological responses were measured using respiratory frequency, rectal temperature, oxygen saturation (Navarro et al. 2006) and white blood cell and differential count (Purnomo et al. 2015). The number of chicken samples observed for rectal temperature and oxygen saturation parameters was 120 male broiler chickens from four areas in each cage in each period, with three maintenance periods as a repeat at 4 weeks of age.

### Production performance

Broiler performance was measured by weighing the chickens at the beginning and end of each maintenance period for three periods. The chicken performance parameters included feed consumption (g/head), weight gain (g/head), feed conversion, mortality (%), and performance index.

### Data Analysis

This study used two cage flooring treatments, namely, a closed house with base litter rice husks and a closed house with plastic slat base. Each treatment was performed in triplicate. The data obtained on the microclimate conditions were descriptively analyzed. Data on air quality, physiological response, and performance were analyzed using a t-test (Independent t-test) (Mattjik and Sumartajaya 2013).

## RESULTS

### Microclimate

The microclimatic conditions of poultry houses play an important role in raising broiler chickens. Table 1 delineates the microclimatic conditions observed within the broiler chicken rearing cages during the study. The data indicated no significant variations, as the recorded values for temperature, humidity, and wind speed were nearly uniform. This is because chickens are raised in closed houses with an automatic environmental regulation system.

**Table 1:** Microclimate conditions in a closed house with different floor types in the 4th week

Microclimate	Litter	Slat
Temperature (°C)	24.3-28.2	24.2-28.1
Humidity (%)	70-92	70-91
Wind speed (m/s)	2.2-2.9	2.1-2.9
THVI (°C)	26.5	26.4

THVI: Temperature humidity velocity index.

### Air quality

The air quality in cages is an important factor in the process of raising broiler chickens. Table 2 presents the air quality data, indicating that the concentrations of ammonia, oxygen, and carbon dioxide in the two study cages did not differ significantly (P>0.05). The concentration of particulate matter (PM)<100µm in cages with a litter base was higher than that in cages with a slat base (P<0.05). This is because the dust in the litter cages originated from rice husk dust particles.

**Table 2:** Air quality of a closed house with different floor types in the 4th week

Air quality	Litter	Slat	P-value
Ammonia (ppm)	0.201±0.135	0.367±0.251	0.057
Particulate matter (PM)<100µm (µg Nm <sup>-3</sup> )	618±21.55 <sup>a</sup>	304±59.65 <sup>b</sup>	0.001
O <sub>2</sub> (%)	20.4±0.3	20.5±0.2	0.875
CO <sub>2</sub> (ppm)	913±254	945.25±232	0.583

Different letters in a row indicate significant differences (P<0.05).

### Physiological response

Table 3 presents the findings of the study, which assessed the physiological response of broiler chickens reared in closed houses with different flooring. The study identified no significant differences in respiratory rate, rectal temperature, oxygen saturation, leukocyte count and differentiation, or heterophil/lymphocyte (H/L) ratio between the two cages examined. The physiological response data from both observations were within the normal range.

**Table 3:** Physiological response of broiler chickens reared in Closed Houses with different flooring

Physiological response	Litter	Slat
Respiratory rate (minutes <sup>-1</sup> )	65.20±5.23	64.30±2.42
Rectal temperature (°C)	41.53±0.60	41.58±0.22
Oxygen saturation (%)	90.20±8.38	91.75±1.94
Leukocyte (×10 <sup>3</sup> /mL)	16.97±2.88	12.82±3.07
Leukocyte differentiation		
Heterophil (%)	29.74±4.22	28.45±3.54
Eosinophil (%)	5.32±1.02	5.21±0.93
Lymphocytes (%)	51.24±6.45	52.43±6.76
Monocyte (%)	13.26±3.11	14.19±3.25
Basophil (%)	ND	ND
Heterophil/Lymphocytes	0.58±0.10	0.54±0.12

### Production performance

The observations of broiler chicken production performance in this study included feed consumption, body weight gain, FCR, mortality, and performance index. Table 4 presents the results of these observations, and the weight gain of broiler chickens raised on a slat base was significantly higher than that of those raised on a litter base (P<0.05). There were no significant differences in feed consumption, FCR, mortality, and performance index between the two treatment cages (P>0.05).

**Table 4:** Performance of broiler chickens raised in Closed Houses with different flooring

Performance parameters	Litter	Slat	P-value
Feed consumption (g/head)	2143±125.29	2238±58.23	0.302
Weight gain (g/head)	1572±49.86 <sup>b</sup>	1632±35.58 <sup>a</sup>	0.003
Feed conversion ratio	1.36±0.04	1.36±0.01	0.894
Mortality (%)	1.82±0.21	1.57±0.33	0.115
Performance index	416±15.88	431±6.03	0.185

Different letters in a row indicate significant differences (P<0.05).

## DISCUSSION

### Microclimate

The climate in a closed house is regulated automatically by climate control. Regulating the climate within enclosed poultry facilities is essential for maintaining optimal living conditions for broiler chickens, thereby ensuring their welfare and productivity. These systems are engineered to automatically control both the ventilation and heating mechanisms to achieve the requisite temperature, which varies according to the age and metabolic requirements of the birds. This dynamic adjustment is critical for optimizing production and ensuring the welfare of animals (Ferreira et al. 2024). This shows that the environmental conditions of the chickens during rearing were still in the comfort zone, with a THVI value of 26.5°C. This is in accordance with Tao and Xin (2003), who stated that broiler chickens with THVI values below 30°C are in the normal range and will not cause an increase in body temperature in broiler chickens. Under conditions within the comfort zone, chickens can grow and develop according to their genetic potential (Kpomasse et al. 2021).

### Air quality

Ammonia is a gas produced by the decomposition of nitrogen by ureolytic bacteria in livestock feces. Ammonia levels within the research cages did not differ, as the rice husks in the litter mat effectively absorbed both moisture and ammonia from feces, thereby preventing their emission into the surrounding air. The same phenomenon occurs in a cage with a plastic slat mat; feces exposed to airflow will directly carry moisture and ammonia into the air, so that the feces under the slat dry faster. Maintaining ammonia levels below 5ppm in broiler-rearing environments is crucial for several reasons. Ammonia is a common contaminant in poultry houses, and elevated levels can have detrimental effects on the health and growth performance of broiler chickens (Han et al. 2021).

Broiler chickens still have the instinct to take dust baths, which causes dust to fly into the air. Unlike cages that use slat flooring, the dust source only comes from feed dust and chicken feathers because the feces under the slats, although drier, are not touched; therefore, they do not have the potential to produce a large amount of dust. High dust concentrations in cages can cause respiratory distress in broilers (Brink et al. 2022).

The oxygen in the poultry house has an exhaust fan with a negative pressure system that can draw oxygen from outside through the inlet. According to the oxygen concentration criteria, low air oxygen concentration is below 19.5% oxygen in the air, and oxygen-rich air is above 23.5% oxygen in the air, meaning that the standard oxygen level in the air ranges from 20 to 23% (Permenaker 2023). The concentration of carbon dioxide (CO<sub>2</sub>) in the air circulation system within the cage, equipped with an exhaust fan, is capable of expelling carbon dioxide from the enclosure. The concentration of carbon dioxide remained within the normal range of less than 3000ppm (Cobb 2021).

### Physiological response

The respiratory rate of the chickens remained consistent owing to the identical microclimatic conditions present in both cages. The frequency of breathing in broiler

chickens is affected by temperature, humidity, and wind speed. A higher temperature will result in the chicken breathing faster to dissipate excess heat in the body because chickens do not have sweat glands (Oke et al. 2020).

The rectal temperature of the animals was within the normal range of 39–41.7°C (Poku et al. 2024). Rectal temperature increases when experiencing heat stress due to high temperature and ambient humidity, so that heat in the body cannot be lowered through heat release through panting, evaporation, convection, radiation, or conduction. In this study, the microclimatic conditions were within the comfort zone of the chickens. This is in accordance with the THVI number, which has the same conditions as the normal range, and the chicken is still in a comfortable condition, so there is no increase in the body temperature of the chicken (Tao and Xin 2003).

Oxygen saturation in broiler chickens is an important physiological parameter that can vary depending on the growth rate and health conditions of the chickens. The normal levels of oxygen saturation indicate that the body is receiving an adequate supply of oxygen (Salam et al. 2025). Oxygen plays a fundamental role in cellular respiration, which is crucial for the growth and metabolism of broiler chickens. Cellular respiration primarily occurs in the mitochondria, where glucose is converted into ATP, the energy currency of the cell. Oxygen is necessary for aerobic respiration, an efficient pathway that produces approximately 36 ATP molecules per glucose molecule. This energy is vital for various physiological functions, including growth, muscle contraction, and homeostasis maintenance by supporting protein, fat, and carbohydrate synthesis (Chen et al. 2022; Almeldin et al. 2024). Additionally, sufficient oxygen levels support the immune system by facilitating the production of reactive oxygen species required for pathogen defense. Oxygen is also pivotal for thermoregulation, as it fuels metabolic reactions that generate heat, thereby helping to maintain body temperature within an optimal range (Abo-Samaha et al. 2022). Low oxygen saturation can increase the potential for ascites in broiler chickens (Ezzulddin 2023).

The normal range of leukocytes in chickens is 6-40 x10<sup>3</sup>/mm<sup>3</sup> grains (Campbell 2015). Factors that affect the number of leukocytes and their differentials include environmental conditions, age, and nutritional content of the feed. (Wang et al. 2024). In this study, the chickens were raised under the same environmental conditions, at the same age, and on the same feed, so they did not experience any differences in these parameters. This shows that chickens raised in both treatment cages had the same potential for immunity against disease-causing agents.

The H/L ratio is an indicator of livestock adaptability to environmental stressors. The heterophil/lymphocyte (H/L) ratio in chickens is an important indicator of stress, health, and resistance to infection. The significance of the H/L ratio at different values (e.g., low, approximately 0.2; normal, approximately 0.5; and high, approximately 0.8) varies and can provide insights into the physiological and immunological status of chickens. Studies have shown that chickens with a low H/L ratio possess more enriched immune pathways and lower levels of antibiotic resistance genes and virulence factors, making them more robust against pathogens. Moreover, chickens with low H/L ratios have a higher survival rate and better immune function,

whereas High H/L ratios are correlated with lower resistance to diseases and reduced immune function (Thiam et al. 2022). The H/L ratio is particularly valuable because it offers an affordable and easily obtainable measure of stress and health status without the need for complex or invasive procedures (Nwaigwe et al. 2020).

### Production performance

Feed intake in broiler chickens is determined by a range of biological, environmental, and management factors. The genetic makeup of broiler chickens significantly influences their feed efficiency, with research identifying quantitative loci within the chicken genome that are associated with feed intake, weight gain, and feed conversion ratio (Marchesi et al. 2021). Environmental temperature also affects feed intake, as heat stress can diminish feed utilization efficiency (Saleh et al. 2021). Furthermore, gut health and balanced microbiota are essential for optimal feed intake (Cho et al. 2024). In this study, the feed composition was consistent across both housing conditions for each experimental phase. Additionally, the microclimatic conditions within the housing facilities showed no variation, resulting in no significant differences in feed intake between groups.

The increase in body weight observed in this study was markedly different. This occurred because there was a difference in the particulate matter (PM) $<100\mu\text{m}$  parameters, where the dust condition was higher in the litter cage than in the slat cage, even though the feed consumption and microclimate of the maintenance cage did not differ between the two groups. Dust can interfere with the respiratory system of chickens, resulting in health problems in the flock. These data are in line with the findings of Almeida et al. (2017), who showed that chickens raised in slat cages had a higher body weight gain than those raised in cages with litter.

The feed conversion ratio is a crucial parameter in broiler chicken production that quantifies the efficiency with which chickens convert feed into their body weight. Various strategies have been explored to optimize FCR, contributing to more sustainable and economical poultry production. The feed conversion ratio (FCR) in broiler chickens is a critical measure of feed efficiency that is affected by various genetic and non-genetic factors (Marchesi et al. 2021).

The absence of differences in mortality parameters was due to identical environmental conditions. Closed house systems facilitate the maintenance of controlled environments that inhibit the introduction and proliferation of pathogens, thereby diminishing dependence on antimicrobials and enhancing overall avian health and productivity. Moreover, the regulation of climate within these enclosures mitigates stress in broilers, which might otherwise compromise their immune systems and increase their disease susceptibility (Caekebeke et al. 2021).

The performance index is a measure of the efficiency of the broiler chicken rearing process. A higher performance index indicates better production performance. A performance index value above 400 is excellent. The performance index is influenced by feed efficiency or feed conversion, body weight, mortality rate, and age. The performance indices of the two research cages are included in this category.

### Conclusion

The results of this study showed that the use of plastic slat flooring in closed houses did not negatively affect broiler chicken rearing. The particulate matter (PM) $<100\mu\text{m}$  concentration in a closed house with a plastic slat base was significantly lower than that with litter flooring. The weight gain of broiler chickens raised in cages with plastic slatted flooring was significantly higher than that of those raised on litter flooring. These findings show that plastic slat flooring is a viable and profitable alternative to rice husks and offers a more sustainable solution for intensive broiler production in the tropics.

### DECLARATIONS

**Funding:** This research received no external funding

**Acknowledgement:** This research was financially supported by the Center for Higher Education Funding and Assessment, Ministry of Higher Education, Science, and Technology of the Republic Indonesia, Endowment Fund for Education Agency (LPDP), Ministry of Finance of the Republic Indonesia, under the Indonesian Education Scholarship (BPI) scheme (contract number 2051/J5.2.3/BPI.06/10/2021). We also thank PT. Hasanuddin Agrivisi Internusa for providing the place and equipment for this research, and Dr. Drh. Tri Isyana Tungga Dewi, M.Si, for the willingness to be an attending veterinarian.

**Conflict of Interest:** The authors declare no conflict of interest.

**Data Availability:** The data sets generated and analyzed during the present study are available within this article.

**Ethics Statement:** All animal handling procedures were approved by the Animal Ethics Committee of the School of Veterinary Medicine and Biomedical Sciences, Bogor Agricultural University, Indonesia (approval number 115 332/KEH/SKE/V/2025).

**Author's Contribution:** This study was made possible by the contributions of all authors. Daryatmo collected information and drafted the manuscript. Niken Ulupi, Rudi Afnan, Ahmad Yani and Hikmah M Ali revised the manuscript. All the authors have read and approved the final version of this manuscript.

**Generative AI Statement:** The authors declare that no Gen AI/DeepSeek was used in the writing/creation of this manuscript.

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### REFERENCES

Abo-Samaha MI, Shukry M, Albogami S, El-Maksoud EMA,

- Alghamdi YS, El-Hack MEA, Soliman MM, El-Shobokshy SA and Farrag F, 2022. Licorice extract supplementation affects antioxidant activity, growth-related genes, lipid metabolism, and immune markers in broiler chickens. *Life* 12(6): 914. <https://doi.org/10.3390/life12060914>
- Ahmad R, Yu YH, Hsiao FSH, Su CH, Liu HC, Tobin I, Zhang G and Cheng YH, 2022. Influence of heat stress on poultry growth performance, intestinal inflammation, and immune function and potential mitigation by probiotics. *Animals* 12: 2297. <https://doi.org/10.3390/ani12172297>
- Almeldin YAR, Eldlebs hany AE, Elkhalek EA, Lohakare J and Abdel-Wareth AAA, 2024. Assessment of dietary supplementation of green iron oxide nanoparticles: impact on growth performance, ammonia emissions, carcass criteria, tissue iron content, and meat quality in broiler chickens under hot climate conditions. *Frontiers in Veterinary Science* 11. <https://doi.org/10.3389/fvets.2024.1393335>
- Almeida EA, De Souza LFA, Sant'Anna AC, Bahiense RN, Macari M and Furlan RL, 2017. Poultry rearing on perforated plastic floors and the effect on air quality, growth performance, and carcass injuries-Experiment 1: Thermal comfort. *Poultry Science* 96(9):3155–3162. <https://doi.org/10.3382/ps/pex131>
- Almeida EA, Sant'Anna AC, Crowe TG, MacAri M and Furlan RL, 2018. Poultry rearing on perforated plastic floors and the effect on air quality, growth performance, and carcass injuries-Experiment 2: Heat stress situation. *Poultry Science* 97(6): 1954–1960. <https://doi.org/10.3382/ps/pey048>
- Anderson K, Ashworth AJ, Martin J and Moore PA, 2021. Evaluation of a novel poultry litter amendment on greenhouse gas emissions. *Atmosphere* 12(5): 563. <https://doi.org/10.3390/atmos12050563>
- [BMKG] Meteorology, Climatology and Geophysics Agency. 2022. Indonesia weather forecast report 2022. Jakarta. BMKG.
- [BPS] Central Statistics Agency, 2025. Indonesian agricultural statistics report 2025. Jakarta. BPS.
- Brink M, Janssens GPJ and Delezee E, 2022. Does feeding more phases reduce ammonia concentrations from broiler litter? *Animal Nutrition* 11: 152–159. <https://doi.org/10.1016/j.aninu.2022.06.020>
- Caekebeke N, Van Den Hoogen A, Ringenier M, Velkers F, Tobias T, Dewulf J, Sleenckx N, Jonquiere F, Postma M, Houben M and Stegeman A, 2021. Coaching Belgian and Dutch broiler farmers aimed at antimicrobial stewardship and disease prevention. *Antibiotics* 10(5): 590. <https://doi.org/10.3390/antibiotics10050590>
- Campbell TW, 2015. In: *Exotic Animal Hematology and Cytology*, John Wiley & Sons, Inc. First edition, USA.
- Chen P, Liu K, Huang S, He Y, Xu T, Tong X, Zhang C and Shaikat A, 2022. Effects of probiotics and gut microbiota on bone metabolism in chickens: A review. *Metabolites* 12(10): 1000. <https://doi.org/10.3390/metabo12101000>
- Cho S, Kumar SS, Ramirez S, Valientes R and Kim IH, 2024. Dietary eubiotics of microbial muramidase and glycan improve intestinal villi, ileum microbiota composition and production trait of broiler. *Journal of Animal Science and Biotechnology* 15(1). <https://doi.org/10.1186/s40104-024-01010-x>
- Cobb [Cobb-Vantress Inc.] 2021. Broiler management guide. Arkansas (US): Cobb-Vantress Inc.
- Corrêa-Junior D, Parente CET and Frases S, 2024. Hazards associated with the combined application of fungicides and poultry litter in agricultural areas. *Journal of Xenobiotics* 14(1): 110–134. <https://doi.org/10.3390/jox14010007>
- Ezzulddin TA, 2023. Ascites in broiler: Updates. *Journal of Applied Veterinary Sciences* 8: 23–29. <https://doi.org/10.21608/javs.2023.175426.1195>
- Ferreira JC, Ferreira SC, Campos AT, Junior TY, Silva JPD, Ferraz PFP and Bahuti M, 2024. Dynamics of the thermal environment in climate-controlled poultry houses for broiler chickens. *Agri Engineering* 6(4): 3891–3911. <https://doi.org/10.3390/agriengineering6040221>
- Gupta CL, Blum SE, Kattusamy K, Daniel T, Druyana S, Shapira R, Krifucks O, Zhu YG, Zhou XY, Su JQ and Cytryn E, 2021. Longitudinal study on the effects of growth-promoting and therapeutic antibiotics on the dynamics of chicken cloacal and litter microbiomes and resistomes. *Microbiome* 9(1). <https://doi.org/10.1186/s40168-021-01136-4>
- Han H, Wang G, Liu Q, Zhang M, Feng J and Zhou Y, 2021. Effects of ammonia on gut microbiota and growth performance of broiler chickens. *Animals* 11(6): 1716. <https://doi.org/10.3390/ani11061716>
- Hoque ME, Aziz M and Rashid F, 2021. Gasification and power generation characteristics of rice husk, sawdust, and coconut shell using a fixed-bed downdraft gasifier. *Sustainability* 13(4): 2027. <https://doi.org/10.3390/su13042027>
- Kpomasse CC, Oke OE, Houndonougbo FM and Tona K, 2021. Broiler production challenges in the tropics: A review. *Veterinary and Medicine Science* 7: 831–842. <https://doi.org/10.1002/vms3.435>
- Lase JA, Afnan R, Wulandari Z, Estuningsih S, Sartika T, Surya, Hayanti SY, Sholikin MM and Sumantri C, 2024. Comparison performance and carcass characteristics of native chicken breeds under free-range and intensive rearing system: A meta-analysis. *International Journal of Veterinary Science* 13(6): 970-979. <https://doi.org/10.47278/journal.ijvs/2024.192>
- Liu L, Ren M, Ren K, Jin Y and Yan M, 2020. Heat stress impacts on broiler performance: A systematic review and meta-analysis. *Poultry Science* 99(11): 6205–6211. <https://doi.org/10.1016/j.psj.2020.08.019>
- Marchesi JAP, Ono RK, Cantão ME, Ibelli AMG, Peixoto JDO, Moreira G CM, Godoy TF, Coutinho LL, Munari DP and Ledur M C, 2021. Exploring the genetic architecture of feed efficiency traits in chickens. *Scientific Reports* 11(1): 4622. <https://doi.org/10.1038/s41598-021-84125-9>
- Mattjik AA and Sumertajaya M, 2013. In: *Experimental design with SAS application and Minitab Volume 1*, IPB Press.
- Navarro PPM, Visscher D, Chatziplis ANM, Koerhuis and Haley CS, 2006. Genetic parameters for blood oxygen saturation, body weight and breast conformation in 4 meat-type chicken lines. *British Poultry Science* 47 (6): pp: 659–670.
- Nwaigwe CU, Nwaigwe CO, Shoyinka SV and Ihedioha JI, 2020. Evaluation of the hematological and clinical biochemical markers of stress in broiler chickens. *Veterinary World* 13(10): 2294–2300. <https://doi.org/10.14202/vetworld.2020.2294-2300>
- Nyakuma BB, Ivase TJP, Mong GR, Wong S, Oladokun O, Wong KY, Abdullah TAT and Utume LN, 2021. Bibliometric analysis of the research landscape on rice husks gasification (1995-2019). *Environmental Science and Pollution Research* 28(36): 49467–49490. <https://doi.org/10.1007/s11356-021-15761-x>
- Ogino A, Setoguchi A, Osada T and Oishi K, 2021. Life cycle assessment of sustainable broiler production systems: effects of low-protein diet and litter incineration. *Agriculture* 11(10): 921. <https://doi.org/10.3390/agriculture11100921>
- Oke OE, Alo ET, Oke FO, Oyebamiji YA, Ijaiya MA, Odefemi MA, Kazeem RY, Soyode AA, Aruwajoye OM, Ojo RT, Adeosun SM and Onagbesan OM, 2020. Early age thermal manipulation on the performance and physiological response of broiler chickens under hot humid tropical climate. *Journal of Thermal Biology* 88: 102517. <https://doi.org/10.1016/j.jtherbio.2020.102517>
- Ornelas-Eusebio E, García-Espinosa G, Laroucau K and Zanella G, 2020. Characterization of commercial poultry farms in Mexico: Towards a better understanding of biosecurity practices and antibiotic usage patterns. *Plos One* 15(12):

- e0242354. <https://doi.org/10.1371/journal.pone.0242354>
- Permenaker, 2023. Regulation of the Minister of Manpower of The Republic of Indonesia number 11 of 2023 concerning occupational safety and health in confined spaces, Jakarta.
- Poku RA, Agyemang-Duah E and Donkor S, 2024. Changes in rectal temperature as a means of assessing heat tolerance and sensitivity in chickens. *Tropical Animal Health and Production* 56: 391. <https://doi.org/10.1007/s11250-024-04242-1>
- Purnomo D, Isroli and Sugiharto, 2015. Total leukocytes and leukocyte differential in broiler chicken blood due to the use of fermented *Rhizopus oryzae* fermented onggok flour in rations. *Journal of Animal Husbandry Sciences* 25(3): 59–68.
- Rodriguez-Otero A, Vargas V, Galarneau A, Castillo J, Christensen JH and Bouyssiere B, 2023. Sustainable harnessing of SiO<sub>2</sub> nanoparticles from rice husks: A review of the best synthesis and applications. *Processes* 11(12): 3373. <https://doi.org/10.3390/pr11123373>
- Salam A, Ulupi N and Maheshwari H, 2025. Stress indicators, immunity and performance of quail during growth period with the supplementation of moringa leaf meal (*Moringa oleifera* L.) in feed. *International Journal of Veterinary Science* 14(4): 737-743. <https://doi.org/10.47278/journal.ijvs/2025.008>
- Saleh AA, Farrag F, Shukry M, Abdel-Moneim AME and Soliman MM, 2021. Effect of feeding wet feed or wet feed fermented by *Bacillus licheniformis* on growth performance, histopathology and growth and lipid metabolism marker genes in broiler chickens. *Animals* 11(1): 83. <https://doi.org/10.3390/ani11010083>
- [SNI] Indonesian National Standards, 2004. Measurement of total dust levels in workplace air. Indonesian National Standard, 16-7058.
- [SNI] Indonesian National Standards, 2005. Exhaust gas emissions. The source is not moving. Part 6: how to test ammonia (NH<sub>3</sub>) levels using the indophenol method using a spectrophotometer. Indonesian National Standard 19-7117.6
- Shahzad K, Ashraf H, Sajjad U, Miyazaki T, Sultan M, Hussain MI, Ali I, Bilal M and Farooq M, 2021. Experiments on energy-efficient evaporative cooling systems for poultry farm application in multan (Pakistan). *Sustainability* 13(5): 2836. <https://doi.org/10.3390/su13052836>
- Shtylla KT, Puvača N, Ljubojević P D, Pelić M, Lika E and Cocoli S, 2023. Colibacillosis in modern poultry production. *Journal of Agronomy, Technology and Engineering Management (JATEM)* 6(6): 975–987. <https://doi.org/10.55817/vzfa3391>
- Tao X and Xin H, 2003. Temperature humidity velocity index for market size broilers. In: *Agricultural and Biosystems Engineering Conference Proceedings and Presentations Agricultural and Biosystems Engineering*. pp: 034037.
- Thiam M, Zhao G, Wen J, Zhang N, Ding J, Li Q, Barreto S, AL, Zhang J, Wang J, Wang Q, Zhang Q and Wang H, 2022. Heterophil/Lymphocyte ratio level modulates salmonella resistance, cecal microbiota composition and functional capacity in infected chicken. *Frontiers in Immunology* 13(2033). <https://doi.org/10.3389/fimmu.2022.816689>
- Wang X, Ding J, Chen K, Hu H, Huang B, Shi G and Li S, 2024. Probing selenium-deficient chicken spleen th1/th17 differentiation based on Selenoprotein W targeting of PKM2/HIF1 $\alpha$ . *Journal of Agricultural and Food Chemistry* 72(44): 24808–24822. <https://doi.org/10.1021/acs.jafc.4c04795>