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Floor position in multitier broiler closed houses and its impact on microclimatic, air quality and litter conditions

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ABSTRACT

This study aimed to evaluate the effects of floor position in a multitier closed house on microclimatic air quality and litter conditions. Fourteen thousand and five hundred unsexed Ross broiler chickens with a DOC body weight of 45.84 ± 2.40 g were placed on each floor of a three-tier closed house and allocated to a randomized block design consisted of 3 treatments and 18 replications. Each floor measured 12x78x2 m^3. The maintenance procedure was applied according to the integrated partnership company guidelines PT Tumbuh Optimal Prima, with an observation period of 28 days. The treatments applied were as follows: T1= placement of broiler chickens on the 1st floor, T2= placement of broiler chickens on the 2nd floor, and T3= placement of broiler chickens on the 3rd floor. Microclimate conditions (temperature, RH, wind speed, temperature humidity index, wind chill effect, and calculated real feel temperature) and air quality parameters (NH_3, CO_2, O_2, TVOC, and HCHO) were measured daily on each floor. Litter conditions, included water content, litter temperature, NH_3 content, pH, and caking were measured weekly. The results revealed that during the starter phase (weeks 1–2), the microclimatic conditions and air quality of the 3rd floor were significantly better ($P<0.05$) than those of the 1st floor and 2nd floor, a trend was continued during weeks 3–4. Notably, the results obtained on the 1st and 2nd floors were still within the normal range for the broiler thermoneutral zone. Conversely, the 3rd floor litter was generally poorer, with significantly higher ($P<0.05$) moisture content, temperature, and caking than the lower floors, particularly in weeks 3–4. However, broiler placement on different floors did not significantly affect the litter pH ($P>0.05$). In conclusion, the microclimatic conditions and air quality of the 3rd floor were generally superior to those of the lower floors over the 4-week rearing period, whereas the litter quality was inferior.

Keywords: *Ammonia, Caking, CO_2, Litter quality, TVOC*

INTRODUCTION

In the early development of closed broiler houses in tropical areas, only a 1-tier design was built; considering the need for land use efficiency and the increased broiler population being maintained, the design was changed to 2 or even 3 tiers to increase production capacity. The position of the floor of the closed house affects the contact of heat received from sunlight on the outside of the house. The 3rd floor, which is generally built in the east–west direction, receives more exposure to sunlight on the outside than do the 1st and 2nd floors, which receive direct exposure on the left and right sides, front and back roofs and top roofs of the house, whereas the floor below only experiences exposure to direct sunlight on the left and right sides and front and back. Irwanto (2015) and Fantami *et al*. (2021) reported, the angle of inclination strongly influences the optimization of solar radiation as well as the minimum temperature throughout the day reached by the surface and contact area. These conditions have the potential to influence the microclimate and air quality on different floors as well as differences in the accumulation of sources and distribution of internal heat in the house, microclimatic conditions, and air quality on each floor. Kic (2016) and Endraswati *et al*. (2019) reported that solar radiation is one of the factors influencing the microclimatic conditions of a house.

There are at least 5 heat contributors in closed house cages, namely, solar radiation, hot air entering through the inlet, especially when the conditions outside the cage are hot, the brooding system, the heat produced by chickens and/or the density of interaction between chickens, and litter with its fermentation mechanism (Kic, 2016). Multitier houses are typically designed with a single-layer litter floor with a tarpaulin base 5–10 cm thick. Therefore, in a 3-floor multitier system, each floor will receive a different heat contribution from waste fermentation products. The 1st and 2nd floors receive heat from fermenting litter from the floors above; apart from functioning as a base, the litter on the 3rd and 2nd floors, which have a tarpaulin base, also doubles as a roof for the floors below. However, the 1st floor has specific conditions because the lowest floor has direct access to the ground surface so that the litter will be relatively cooler than the 2nd floor. This condition is thought to result in differences in the heat contribution of litter fermentation between floors, especially in the early weeks of the maintenance period, potentially resulting in differences in microclimatic conditions. The control panel system on each floor operates independently on each floor on the basis of input from an absolute temperature sensor, with different wall, floor and roof constructions potentially contributing to variations in the effectiveness of microclimate regulation across the floors.

The macroclimate also causes fluctuations in microclimate conditions and air quality in the house, so it must be controlled intensively via the control panel. The high temperature during the day may increase the temperature inside the cage (Endraswati *et al*., 2019; Fantami *et al*., 2021; Kic, 2016; Šikula and Plášek, 2008). Fluctuations and changes in the macroclimate and microclimate of the house can result in an increase in the heat increment of chickens, resulting in heat stress (Hardianti *et al*., 2019; Lara and Rostagno, 2013), decreased performance (Fantami *et al*., 2021; Jannah *et al*., 2020) and profits obtained by farmers. Heat stress can affect the digestibility of feed protein, bypass undigested protein, and increase water intake so that more of the main ingredients for litter fermentation are available (Bimo *et al*., 2020). Additional physical operational management mechanisms, such as water sprinkle settings to reduce housing temperature, especially during the day, are regulated and integrated into a closed-house control panel that operates independently on each floor, which may also contribute to variations in litter humidity and reduce litter quality. Litter with high water content and excreta with high uric acid can cause fermentation by microorganisms that produce NH_3, H_2O, and CO_2 products (Kuter *et al*., 2023). Kaukonen *et al.* (2016) and Opengart *et al*. (2018) reported that a decrease in litter quality in both broiler and breeder cages resulted in an increased risk of Foot Pad Dermatitis (FPD). This increased risk occurs due to irritation of skin areas that come into direct contact with the irritant material. Contact dermatitis, which results in skin damage, is a common problem that reduces the welfare of broilers and is believed to also affect broiler breeders.

Research related to microclimate distribution and litter quality at different pen positions and closed house lengths has been reported by several researchers (Huda *et al*., 2021; Küçüktopcu *et al*., 2022; Küçüktopçu *et al*., 2024), but few studies have provided comprehensive reports on changes in microclimate conditions, air quality, and wind speed distribution in closed houses with a 3-tier floor system. This research aims to evaluate the influence of the placement of a 3-tier closed house floor on microclimatic conditions and air quality and its impact on changes in litter quality so that it can be used to optimize the performance of broiler chickens maintained in a multitier closed house. The hypothesis of this research is that placement in the 3rd floor has a better impact on microclimatic temperatures and air quality than does placement in the 1st floor or 2nd floor.

MATERIALS AND METHODS

Animal Husbandry

The observations were carried out in a three -floor, multi-tier, closed broiler house with a volume of each floor of 12x78x2 m^3. During the rearing phase, 14,500 unsex Ross broilers with a DOC body weight of 45.84 ± 2.40 g were placed on each floor of a three-floor multitier closed house and allocated to a randomized block design of three treatments and 18 replications. Before rearing, the broiler house and equipment was sanitized and sprayed with disinfectant water mixed with Septocid, and the entire floor surface was sown with litter made from rice husks. The brooding area was arranged via a central heating system. Temperature and wind speed was adjusted based on Ross broiler management guide (Aviagen, 2018). The curtain system, water, and feeding system were installed before the DOC arrived. For the first 8 hours (h), chicks were provided extra commercial electrolytes through drinking water (4 l/300 l of water) and 1 gram of Carmavit per 2 liters of water afterwards. Each floor of the house was divided into 3 pens. Feed was provided *ad libitum*, according to the standard operating procedures of PT Tumbuh Optimal Prima. Litter adjustment and resown were carried out every 2 days, and from day 20 onwards, zeolite was sown every 2 days at a dose of 0.64 kg/ m^2.

Microclimate conditions and air quality parameters, including temperature, humidity, wind speed, wind chill effect, ammonia, carbon dioxide, oxygen, PM2.5, TVOC, HCHO, temperature –humidity index, and real feel temperature, were measured thrice daily at 8-hour intervals (05:00, 13:00, and 21:00 WIB) for 4 weeks. Litter conditions were assessed weekly for 4 weeks at the ages of 1, 7, 14, and 28 days. Litter samples were taken from each experimental group, and parameters such as litter water content, litter temperature, ammonia content, litter pH, and percentage of caking litter were observed. Protein consumption was calculated on the basis of feed protein content at each rearing stage, whereas bypass protein consumption was estimated on the basis of broiler protein digestibility in closed-house systems, as reported by Bimo *et al*. (2020). Stocking density was calculated on the basis of the ratio of body weight at the time of observation to the available space, whereas estimated heat production was calculated on the basis of heat production per kg BW, as reported by Noblet *et al*. (2015). Finally, foot pad dermatitis scores were also determined to understand the impact of litter conditions on the health of the feet of broiler chickens on each floor.

Data Analysis

The analysis of variance was performed with SAS JMP software version 13 at a significance level of 5%. The significant data were subsequently tested via Tukey's honestly significant difference (HSD) test to determine differences between treatments. Correlation analysis was also conducted to understand the relationships between parameters.

RESULTS AND DISCUSSION

Microclimate and Air Quality

The floor position in a closed-house cage significantly affected the absolute temperature, air humidity, windchill effect, THI, and calculated real feel temperature ($P<0.05$). However, there was no significant difference in the wind speed ($P>0.05$). Air quality, in the form of microclimatic ammonia, carbon dioxide, oxygen, PM2.5, TVOC, and HCHO, was influenced by the floor position inside a closed broiler house ($P<0.05$). In general, the microclimate conditions and air quality on the 3rd floor in both the first and second weeks were more conducive to supporting the fulfilment of thermoneutral zone standards and air quality for brooding-phase broilers. The statistical results of the microclimate conditions and air quality on different floors in a closed broiler house are presented in Table 1.

In the third and fourth weeks, the microclimate conditions in the third floor were more conducive than those in the other floors that was similar to the air quality ($P<0.05$). In principle, the optimum number of operating direct fans in the third floor is attained at a younger age of poultry than those in the other floors. Therefore, the operation of direct fans ran faster in the 3rd floor than in the other floors, resulting in the av-

Table 1. Microclimate Conditions and Air Quality of Different Floors in a Closed Broiler House

Parameter	Week(s)															
	1st				2nd				3rd				4th			
	1st Floor	2nd Floor	3rd Floor	Pval	1st Floor	2nd Floor	3rd Floor	Pval	1	2	3	Pval	1	2	3	Pval
Microclimate conditions																
Absolute tempe rature(°C)	33.47±2.44^{B}	33.64±2.45^{B}	34.02±2.50^{A}	<.00	31.89±2.96	31.91±2.96	32.04±2.97	0.49	27.36±1.03^{B}	27.79±1.05^{A}	27.39±1.04^{B}	<.01	26.87±0.92^{B}	27.19±0.94^{A}	26.63±0.92^{C}	<.01
RH (%)	73.29±20.15^{B}	74.89±20.59^{A}	72.82±20.02^{B}	<.00	72.62±17.93^{C}	76.51±18.89^{B}	79.12±19.54^{A}	<.00	91.72±12.6^{B}	90.76±12.52^{C}	92.76±12.80^{A}	<.01	89.57±9.31^{B}	89.76±9.33^{B}	92.0±9.56^{A}	<.01
Wind Speed (m/s)	0.08±0.0002	0.2±0.0006	0.4±0.0120	0.16	0.2±0.0018^{C}	0.4±0.0036^{B}	0.7±0.0063^{A}	<.00	1.80±0.018^{C}	1.97±0.020^{B}	2.17±0.022^{A}	<.01	2.76±0.04^{b}	2.81±0.04^{b}	3.24±0.05^{a}	0.04
Windchill effect	-0.4±0.0008^{c}	-0.45±0.0009^{b}	-0.5±0.0010^{a}	0.02	-0.389±0.003^{B}	0.399±0.003^{B}	0.447±0.004^{A}	<.00	-6.85±0.32^{C}	-7.67±0.36^{B}	-8.66±0.40^{A}	<.01	-10.9±0.06	-10.95±0.60	-10.79±0.59	0.12
Temperature Humidity Index	165.55±37.6^{B}	167.45±38.01^{A}	166.06±37.7^{B}	<.00	162.04±35.48^{C}	165.97±36.3^{B}	168.8±36.96^{A}	<.00	162.05±11.5^{A}	161.11±11.4^{B}	160.22±11.47^{C}	<.01	162.21±9.89^{B}	163.03±9.94^{A}	164.01±10.00^{A}	<.01
Real feel Temperature (°C) *	33.07±2.41^{B}	33.24±2.42^{B}	33.62±2.45^{A}	<.00	31.49±2.99	31.51±2.99	31.59±3.00	0.74	20.51±1.10^{A}	20.11±1.08^{B}	18.73±1.01^{C}	<.01	15.96±1.27^{B}	16.24±1.29^{A}	15.84±1.26^{C}	<.01
Air Quality																
Microclimatic NH_3 (ppm)	0.08±0.0005^{A}	0.018±0.0002^{C}	0.05±0.0002^{B}	<.00	0.16±0.004^{B}	0.158±0.004^{B}	0.31±0.076^{A}	<.01	0.409±0.01^{B}	0.437±0.001^{B}	0.733±0.01^{A}	<.01	0.97±0.01^{A}	0.96±0.02^{A}	0.82±0.02^{B}	<.01
CO_2 (ppm)	1532±32.99^{C}	1737±37.09^{B}	2180±46.94^{A}	<.00	1449±19.8^{C}	1591±21.83^{B}	1793±24.51^{A}	<.01	1038±4.66^{A}	1009±4.53^{B}	931±4.18^{C}	<.01	977±17.00	1012±17.65	954±16.60	0.08
O_2 (%)	20.65±0.61^{A}	20.36±0.61^{B}	20.28±0.60^{B}	<.00	20.53±0.53^{A}	20.22±0.52^{B}	20.41±0.53^{B}	<.01	20.9±18.18^{A}	20.0±17.40^{B}	19.8±17.22^{C}	<.01	20.33±0.42	20.27±0.42	20.29±0.42	0.16
PM2.5 (ppm)	77.41±50.61^{A}	64.73±42.33^{B}	63.96±41.82^{B}	<.00	78.14±58.4^{B}	76.19±56.9^{B}	81.55±60.9^{A}	<.01	43.56±22.07^{A}	38.68±19.6^{B}	38.79±19.7^{B}	<.01	41.50±17.38^{A}	40.16±16.82^{A}	38.46±16.11^{B}	<.01
TVOC (mg/m^3)	0.147±0.001^{B}	0.195±0.002^{A}	0.18±0.0015^{B}	<.00	0.13±0.001^{B}	0.16±0.02^{AB}	0.18±0.002^{A}	0.01	1.30±0.23^{B}	2.04±0.36^{A}	0.02±0.003^{C}	<.01	0.02±0.0002^{AB}	0.03±0.0003^{A}	0.021±0.0002^{B}	0.01
HCHO (mg/m^3)	0.05±0001^{C}	0.09±0.0003^{A}	0.08±0.0002^{B}	<.00	0.60±0.018	0.05±0.0002	0.1±0.0003	0.09	0.17±0.006^{B}	0.38±0.01^{A}	0.01±0.0005^{C}	<.01	0.010±0.0001	0.010±0.0001	0.008±0.00005	0.10

Different superscripts on the same row indicate significant differences ($P<0.05$).
*Real feel temperature = temperature humidity index – wind chill value.

Table 2. Calculated protein intake, calculated bypass protein, body weight, stocking density and estimated heat production, which potentially affect litter quality in different floor tiers

Parameter	Week(s)															
	1st				2nd				3rd				4th			
	1	2	3	Pval	1	2	3	Pval	1	2	3	Pval	1	2	3	Pval
Feed Intake (g/bird/w)	172.69±2.33^{A}	163.49±2.21^{B}	152.31±2.06^{C}	<.01	472.47±9.30^{A}	487.54±9.60^{B}	426.25±8.38^{C}	<.01	951.39±56.41^{C}	1030.10±61.08^{B}	1229.01±72.88^{A}	<.01	1805.29±90.08^{C}	1869.73±93.30^{B}	2037.19±101.66^{A}	<.01
Calculated Protein Intake (g/bird/w)	34.00±0.22^{B}	38.33±0.28^{A}	33.04±0.23^{C}	<.01	94.80±0.33^{C}	106.73±0.72^{B}	108.52±0.16^{A}	<.01	219.44±1.16^{C}	233.26±0.37^{B}	269.04±1.52^{A}	<.01	374.78±1.08^{C}	388.16±0.14^{B}	422.43±0.98^{A}	<.01
Calculated Bypass Protein*(g/bird/w)	8.09±0.05^{B}	9.12±0.07^{A}	7.86±0.05^{B}	<.01	22.56±0.08^{C}	25.40±0.12^{B}	25.830.04^{A}	<.01	52.23±0.27^{C}	55.52±0.09^{B}	64.03±0.36^{A}	<.01	89.20±0.26^{C}	92.38±0.03^{B}	100.66±0.23^{A}	<.01
Body Weight (g)	136.33±2.48^{C}	151.67±2.76^{B}	164.66±3.00^{A}	<.01	396.39±4.99^{B}	381.22±19.02^{C}	461.81±23.04^{A}	<.01	842.11±71.07^{B}	845.11±71.33^{B}	981.67±82.85^{A}	<0.1	1477.72±99.30^{C}	1556.50±104.60^{B}	1605.56±107.89^{A}	<.01
Calculated stocking density **(kg/m^{2})	4.21±0.07	4.68±0.06	5.08±0.08	NA	8.10±0.12	7.77±0.09	9.40±0.14	NA	12.83±0.17	12.83±0.13	14.91±0.19	NA	22.43±0.17	23.56±0.08	24.27±0.12	NA
Estimate heat production*** (kJ/kg bird/day)	105.54±0.76^{C}	113.68±0.65^{B}	120.41±0.83^{A}	<.01	222.29±2.07^{B}	216.33±1.63^{C}	247.41±2.32^{A}	<.01	375.45±3.60^{B}	374.28±2.68^{B}	419.35±3.95^{A}	<.01	557.56±3.53^{C}	584.56±1.67^{B}	593.76±2.49^{A}	<.01

Different superscripts on the same row indicate significant differences (P<0.05).
*Calculated based on total protein digestibility of broilers raised in a tropical environment closed house (76.2%) (Bimo et al. 2020); Bypass protein = protein intake – protein digestibility
** NA of the calculated stocking density means that no analysis of variance was carried out. only descriptively means provided
*** Estimates total heat production based on a body weight equal to 425 kJ/kg/day (Noblet *et al.*(2015)

Table 3. Closed-House Litter Quality as Affected by Floor Placement

Parameter	Age (Week)															
	1st				2nd				3rd				4th			
	Floor Placement															
	1st Floor	2nd Floor	3rd Floor	Pval	1st Floor	2nd Floor	3rd Floor	Pval	1st Floor	2nd Floor	3rd Floor	Pval	1st Floor	2nd Floor	3rd Floor	Pval
Water (%)	18.21 ± 0.11	24.06 ± 0.13	22.4 ± 0.18	0.79	22.95 ± 0.12	23.93 ± 0.14	22.4 ± 0.18	0.12	20.51 ± 0.11^{B}	17.54 ± 0.16^{B}	30.49 ± 0.16^{A}	<.01	19.24 ± 0.09^{B}	21.08 ± 0.09^{B}	29.53 ± 0.07^{A}	<.01
Temperature (^{0}C)	33.24 ± 0.80^{B}	32.12 ± 0.61^{C}	33.92 ± 0.45^{A}	<.01	35.29 ± 0.96	33.34 ± 2.34	33.28 ± 0.89	0.07	33.16 ± 0.68^{B}	33.76 ± 0.54^{B}	36.24 ± 1.49^{A}	<.01	32.33 ± 0.33^{C}	33.81 ± 0.93^{B}	34.47 ± 1.17^{A}	<.01
NH_3 (ppm/g)	-------------- *Not detected* --------------				0.17 ± 0.07	0.17 ± 0.10	0.13 ± 0.06	0.22	0.14 ± 0.04	0.14 ± 0.05	0.20 ± 0.09	0.26	0.12 ± 0.05^{C}	0.17 ± 0.06^{B}	0.35 ± 0.10^{A}	<.01
pH	6.64 ± 0.40	6.69 ± 0.25	6.81 ± 0.27	0.76	7.08 ± 0.25	7.21 ± 0.30	7.32 ± 0.52	0.60	7.35 ± 0.20	7.38 ± 0.32	7.59 ± 0.31	0.16	7.48 ± 0.41	7.77 ± 0.57	8.02 ± 0.40	0.08
Caking (%)	2.8 ± 0.25	3.70 ± 0.14	2.13 ± 0.32	0.52	8.08 ± 0.15	8.78 ± 0.18	13.9 ± 0.19	0.62	7.99 ± 0.14^{B}	8.09 ± 0.17^{B}	18.06 ± 0.09^{A}	<0.01	19.24 ± 0.09^{B}	21.08 ± 0.08^{B}	29.53 ± 0.06^{A}	<.01
Score FPD	-	-	-	-	-	-	-	-	-	-	-	-	0.55 ± 0.19^{B}	0.64 ± 0.18^{B}	0.91 ± 0.16^{A}	<.01

Different superscripts in the same row indicate significant differences (P<0.05) erage effective microclimate conditions being more conducive than those on the other floors, especially in the third week. The significantly better average wind speed contributes positively to the calculated decrease in absolute temperature and the wind chill factor, increasing the comfort of poultry. A relatively high average wind speed also increased the microclimatic elimination rates of ammonia, PM2.5, and TVOC, thereby improving the air quality.

In the first week, the 3rd floor, especially during the daytime, more easily achieves the target microclimate conditions due to the significant contribution of higher solar radiation, making brooding temperature targets easier to achieve. In our research, the performance of the brooders in the 3rd floor also proved to be more efficiently meet the ideal temperature targets. Compared to other floors, the larger surface area exposed to solar radiation in the 3rd floor likely facilitates the achievement of higher absolute temperature targets. Data from the Ministry of Energy and Mineral Resources (Kencana *et al*., 2018) indicates that Indonesia experiences an average global horizontal irradiation (GHI) of 4.8 kWh/m2. This value is relatively evenly distributed across Indonesia's regions, with minimal seasonal fluctuations throughout the year (Silalahi *et al*., 2021). GHI values are calculated based on the total shortwave radiation received from above by a horizontal surface on the ground. Therefore, technically, compared with the other floors, the 3rd floor experiences notably better conditions during the brooding period.

Broiler chickens in the brooding phase require additional environmental heat for optimal development and supporting optimal broiler growth. The ideal microclimate conditions during the brooding period for broiler chickens are a temperature of 33 °C, relative humidity (RH) of 65%, and a wind speed of 0.1 m/s; providing an ideal brooding environment (Vantress, 2018;Fantami, Baba, and Abdullahi, 2021). Floor 3 has significantly lower humidity than does floor 2 ($P<0.05$). When combined with a relatively higher average wind speed ($P>0.05$), this condition provides better environmental conditions than other floors do. Based on the calculations performed, the significantly higher THI value in floor 3 is a positive indicator for broiler chickens in the brooding phase. Although not significantly different, the more intense operation of the exhaust fan in the 3rd floor results in a higher wind speed, improving heat distribution and more effectively eliminating hazardous gases than in other floors. This is demonstrated by the lower levels of microclimatic ammonia, carbon dioxide (CO_2), PM2.5, TVOC, and HCHO.

Volatile organic compounds was easily evaporated into the air (David and Niculescu, 2021). Moreover, excessive concentrations of VOCs from metabolized and fermented litter can decrease performance, preventing broilers from reaching standard body weight in the first week (Li *et al*., 2017). We attempted to examine the relationship between microclimate and air quality via a correlation test. We found a positive correlation between absolute temperature, wind speed, humidity, wind chill, THI, real feel, PM2.5, TVOC, HCHO, oxygen, carbon dioxide, and ammonia followed a consistent pattern from week 1 to week 4 (the results of the analysis are presented in Appendix 1).

We suspect that the 3rd floor more easily achieves the target brooding temperature due to the direct influence of solar radiation. This also results in more frequent operation of the fans, which enhances air circulation within the coop. In addition, the increased air movement improves the oxygen supply for the chickens in this floor. The higher wind speed in the 3rd floor contributes to a more uniform distribution of brooding heat across all coop areas, optimizing the chickens' body weights. Chick activities and distribution during brooding are influenced by factors such as temperature and wind speed (Cobb – Vantress, 2018), which can ultimately affect their feed intake and weight gain (Leksrisompong *et al*., 2009). As presented in Table 2, the body weights of the chickens in the 3rd floor consistently and significantly increased compared with those in the other floors.

Energy efficiency to achieve the closed-house target temperature can be estimated based on the amount of gas used as brooder fuel. We calculated the gas fuel consumption over three rearing periods, as presented in Table 4, which shows the average amount of gas fuel used per period. Gas consumption in the 3rd floor was lower than that in the first and second floors. Technically, during the brooding period, the first and second floors require an average of 2 to 4

Table 4. Average Volume of LPG Used During the Brooding Phase ~~of~~ in the 3 different floor of broiler maintenance periods.

Maintenance Periods	Floor		
	----------- kg -----------		
	1	2	3
Pre research	1.800	1.750	1.700
Research	1.950	1.850	1.750
Post research	1.950	1.850	1.800
Average	1.900	1.816	1.750

LPG usage is calculated in kg; every 1 gas cylinder ~ 50 kg volume

more gas cylinders than the 3rd floor does. Šikula and Plášek (2008) stated, under appropriate conditions and calculations, solar energy can contribute to meet energy needs, effectively heating a coop's microclimate, thus improving energy efficiency and reducing costs.

However, the overall air quality in the 3rd floor was better due to a higher pollutant elimination rate, although its litter condition was worse than that in floors 1 and 2. This is likely due to a greater potential for litter fermentation, resulting from the higher amounts of uric acid from excreta and undigested feed. Broiler chickens raised in the 3rd floor exhibit greater growth and body weights, leading to increased feed consumption and undigested feed output. A greater body weight also implies an increase in stocking density. As is commonly known, the average protein digestibility in broilers is only around 80%. However, total feed intake increases in proportion to body size. A high stocking density also reduces heat loss efficiency, which is typically followed by increased water consumption and wetter droppings. As reviewed by Salim *et al*. (2014), excess undigested N from both feed and supplements can increase N excretion and ammonia emissions, especially in the absence of sufficient nitrification mechanisms. Heat production from sunlight, litter fermentation, and broiler body temperature are also believed to enhance ammonia volatilization and the release of gases such as TVOC and HCHO from fermentation. This leads to further deterioration in litter quality. Data about the decline in litter quality and its impact on FPD incidence are presented in Table 3.

Litter Quality

The litter temperature in the 3rd floor was significantly higher ($P<0.05$) than that in the 1st and 2nd floors, except during the 1st week. Except for the litter temperature in the 1st week, no significant differences were observed in the litter quality parameters (water content, NH_3, pH, and caking percentage) during weeks 1-2 ($P>0.05$). The statistical results of the litter quality are presented in Table 3.

The litter temperature in the 3rd floor was higher than that in the 1st and 2nd floors during the first week. This occurred because the litter temperature is directly proportional to brooder temperature. Compared to the 1st and 2nd floors, the 3rd floor achieved a more effective temperature microclimate, with an average temperature of 34.02 °C. In contrast, the 1st and 2nd floors recorded have an average temperatures of 33.47 °C and 33.64 °C, respectively (Table 1). Yerpes *et al*. (2020) clarified, the temperature achieved in a cage during the brooding period is influenced by both the brooder and litter temperatures. The achievement of a better effective temperature on the 3rd floor is due to the construction and physical condition of the multitier closed-house building, which allows the 3rd floor to absorb heat from solar radiation on the s walls and roof, along with higher light intensity, especially during the day. As a result, the temperature regulation on the 3rd floor is more effective.

The Cobb Vantress management guide (Cobb - Vantress, 2018) indicated, the ideal temperature and humidity for broilers at 7 days of age are 34 °C and 40–60%, respectively. Although brooder operations are regulated by temperature sensors, achieving the effective temperature within the cage can be challenging due to the large volume of the cage. Therefore, the additional solar radiation in the 3rd floor during the day helps to maintain the optimal temperature during the brooding period. Factors such as temperature, air humidity, wind speed, and solar radiation outside the cage can significantly influence the microclimate within, including tempera-

Appendix 1. Correlation between Microclimate and Air Quality during Rearing Periods

1st week

Microclimate	Air quality					
	Ammonia	CO_2	O_2	PM2.5	TVOC	HCHO
	------------------ r value ------------------					
Temperature	0.400**	0.794**	-0.407**	-0.056	0.653**	0.677**
RH	-0.217	-0.136	0.035	-0.012	0.222	0.354**
AV	0.116	0.149	-0.190	-0.240	-0.084	-0.037
Windchill	Not detected					
THI	0.107	0.447**	-0.258	0.727	0.636**	0.759**
Real Feel	0.400**	0.795**	-0.407**	0.687	0.653**	0.677**

2nd week

Microclimate	Air quality					
	Ammonia	CO_2	O_2	PM2.5	TVOC	HCHO
	------------------ r value ------------------					
Temperature	0.425**	0.755**	-0.523**	0.261	0.833**	0.828**
RH	0.471**	0.591**	-0.434**	0.295*	0.262	0.002
AV	0.395**	0.503**	-0.299*	0.368**	0.248	0.091
Windchill	-0.22	-0.236	0.199	-0.335*	-0.106	-0.017
THI	-0.599**	0.831**	-0.599**	0.364**	0.572**	0.338*
Real Feel	0.412**	0.740**	-0.510**	0.242	0.825**	0.825**

3rd week

Microclimate	Air quality					
	Ammonia	CO_2	O_2	PM2.5	TVOC	HCHO
	r value					
Temperature	0.573**	0.740**	0.701**	0.612**	0.682**	0.675
RH	-0.113	-0.758**	-0.658**	-0.413**	-0.834**	-0.803**
AV	0.728**	-0.151	0.123	-0.051	-0.183	-0.091
Windchill	0.721**	0.164	-0.12	0.07	0.189	0.095
THI	0.159	0.875**	0.482**	0.725**	0.651**	0.528**
Real Feel	-0.405**	0.588**	0.277	0.420**	0.581**	0.481**

4th week

Microclimate	Air quality					
	Ammonia	CO_2	O_2	PM2.5	TVOC	HCHO
	r value					
Temperature	0.868**	0.661**	-0.153	0.869**	0.900**	0.822**
RH	-0.569**	-0.364**	-0.02	-0.453**	-0.450**	-0.407**
AV	0.523**	0.351**	-0.351**	0.446**	0.523**	0.335*
Windchill	-0.407**	-0.235	0.273*	-0.378	-0.409**	-0.239
THI	0.791**	0.583**	-0.299*	0.781**	0.824**	0.747**
Real Feel	0.568**	0.490**	0.049	0.590**	0.598**	0.646**

Significance level P (<0.01) **
P (>0.05) *

ture, humidity, and wind speed, as identified by Farhadi and Hosseini (2014) and Endraswati *et al.* (2019).

Litter water content, NH_3 levels, pH, and litter caking percentages in the 1^{st} week of maintenance did not show significant differences, indicating that the litter quality remained good. Broiler chickens in the starter phase consume less feed and produce fewer uric acid byproducts than do broiler chickens in the finisher phase. Therefore, litter fermentation did not occur effectively in the first week. Effectiveness of the 3^{rd} floor's house temperature which is better than those of the 1^{st} and 2^{nd} floors in the starter period, also resulting in greater body weight (Table 2). Fatmaningsih *et al.* (2016) stated, management practices carried out during the brooding period can significantly influence body weight development and are a key determinant of performance in subsequent growth stages litter water content, temperature, NH_3 levels, pH, and caking percentage in the second week did not differ significantly (Table 3). The litter's quality and water-binding capacity in the second week remained good. The high litter and cage cleanliness observed during this period were likely due to the relatively low amount of excreta produced by the chickens, along with effective litter management practices, such as adjusting the litter and adding husks every two days. This is in accordance with the findings of Marang *et al.* (2019), who reported that microbial fermentation activity in litter is hampered when the litter remains in good and clean condition. The litter water content in the second week was still within normal limits. This is in accordance with Dunlop *et al.* (2015), who reported that the maximum acceptable water content in litter is 30–35%. The litter was still able to absorb cage moisture effectively, resulting in no significant differences. Shepherd *et al.* (2017) stated, excess moisture in a cage can be absorbed by the litter if the litter conditions are good enough.

Closed-house physical management is designed on the basis of the target physiological needs of the broilers. In the 2^{nd} week, the heater was turned off, while the water sprayer on the cell deck has not yet been activated. These microclimate adjustments were still insufficient to significantly affect litter quality. Boďo and Gálik (2018) clarified, the microclimatic conditions of closed houses can influence the fermentation rate of litter. Broiler chickens housed in environmentally controlled conditions that meet their physiological needs can grow and develop more optimally. Pires *et al.* (2020) reported, the physiological activity of broiler chickens is influenced by both internal closed-house factors and physiological state, allowing for optimal performance. Litter water content, temperature, and caking percentage in the 3^{rd} floor were significantly higher ($P<0.05$), while there were no significant differences between the 1^{st} floor and 2^{nd} floors ($P>0.05$). However, the litter NH_3 concentration and pH did not show significant differences in the second week.

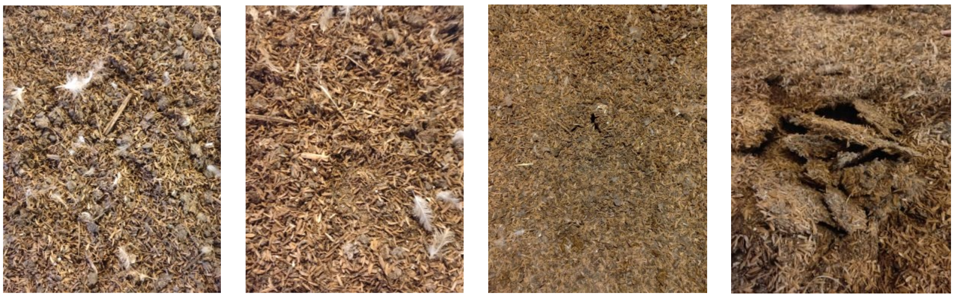
The decline in litter quality began in the third week due to the operation of the water sprayer on the cell deck, which affected the microclimate, particularly the temperature and wind speed in the cage. The higher intensity of sunlight in the 3^{rd} floor, due to direct exposure to sunlight on the sidewalls and roof, was mitigated by increased wind speeds in the 3^{rd} floor during the third week. Notably, the fully automated fans in the 3^{rd} floor were operated earlier than those in the 1^{st} and 2^{nd} floors. Wijaksana *et al.* (2017) stated, high air velocity can help reduce the effective temperature inside a house. Compared with those in the 1^{st} and 2^{nd} floors, the higher wind speed in the 3^{rd} floor induced a wind chill effect, making the environmental conditions more comfortable for the broilers and resulting in higher protein consumption in the 3^{rd} floor (Table 1). In accordance with Sandyawan and Putra (2019), the wind chill effect reflects the actual temperature felt by chickens. Zajicek and Kic (2013) stated, the wind chill effect can decrease the effective temperature by 5.5–7.0 °C. The actual temperatures in the $1^{st,}$ 2^{nd}, and 3^{rd} floors were 20.51 °C, 20.11 °C, and 18.73 °C, respectively. The wind chill effect in the 3^{rd} floor was 26.42% and 12.90% higher than those in the 1^{st} and 2^{nd} floor, respectively, in the third week (Table 1).

In the third week of maintenance, the average litter temperature was significantly higher in the 3^{rd} floor than in the other floors. This is likely due to higher heat production in the 3^{rd} floor. Broilers in the 3^{rd} floor also had a significantly higher average body weight. These findings suggest an increase in both stocking density and heat production. The estimated broiler heat production in the third week in the 3rd floor was 11.70% and 12.64% higher than that in the 1st and 2nd floors, respectively (Table 2). Knizatova *et al*. (2010) and Pepper *et al*. (2021) stated, an increase in litter temperature can be influenced by heat generated from litter fermentation or through contact and heat transfer between broilers and the litter. An increase in the body's metabolic activity also contributes to higher heat production. Baracho *et al*. (2011) and Endraswati *et al*. (2019) clarified, heat produced by broiler metabolism is a significant source of heat in closed houses. Higher heat production in the 3rd floor than on floors 1 and 2 may also lead to an increase in water consumption, which in turn affects the moisture content of excreta, resulting in a greater increase in the litter moisture content in the 3rd floor than in the 1st and 2nd floors (Table 3). Bruno *et al*. (2011) stated, the water consumption patterns of broilers are influenced by the type of drinker and the environmental temperature. The deterioration in the litter condition, in the form of a higher percentage of caking in the 3rd floor in the third week, coincided with the increase in the moisture content in the litter. This is in accordance with the findings of Yamak *et al*. (2016), who reported that caking occurs when the litter's capacity to absorb the excess moisture content is exceeded, particularly in high-humidity environments. The decline in litter quality, as indicated by the increased caking is presented in Figure 1.

Litter NH_3 levels and pH did not have significant differences in the third week. However, there was an increase in the litter moisture content and temperature, which was not sufficient to increase the fermentation process. Litter fermentation typically occurs in high-humidity environments supported by the presence of uric acid, from undigested feed. Saputra *et al*. (2020) reported, the main ingredients required for litter fermentation are uric acid, H_2O, and O_2, with the resulting byproducts being heat, NH_3, and CO_2. Starting at the 20th day of maintenance, we implemented additional management strategies, included litter scraping and zeolite application. Zeolite was used to absorb water and bind ammonia in the litter. Elsherbeni *et al*. (2024) stated, zeolite chemically absorbs ammonia through aluminosilicate minerals and functions as a water absorber, dryer, and cation exchanger. Elsherbeni *et al*. (2024) stated, zeolite is a hydrated aluminosilicate that contains alkali/alkaline earth cations in the form of a 3-dimensional framework, characterized by its acidic and molecular-sized pores. In this study, the zeolite dose applied was 0.64 kg/m^2, below the recommended dose of 5 kg/m^2 by Kardaya and Ulupi (2006). Pillai *et al*. (2012) stated, litter treated with a 25% zeolite dose can reduce TVOC levels in the house.

Litter moisture, caking percentage, and FPD scores were significantly higher in the 3rd floor ($P<0.05$). However, there were no significant differences between the 1st and 2nd floors. Litter temperature and NH_3 levels in the 3rd floor were also significantly higher ($P<0.05$) than those in the 1st and 2nd floors. However, the litter pH did not significantly differ in the fourth week. The higher increase in litter temperature in the 3rd floor than on the 1st and 2nd floors indicated the onset of the litter fermentation, caused by the accumulation of uric acid and H2O in week 4. Yarazel *et al*. (2021) reported, the litter fermentation process generates heat, which can serve as a source of warmth in broiler houses. The relatively high litter temperature in the 3rd floor was proportional to the high-water content in the fourth week. This occurred because fermentation in high-moisture-content litter, supported by the presence of uric acid, accelerates heat production. The litter moisture content did not decrease during the 4th week, likely because the proportion of H_2O needed for fermentation was less than the increase in moisture due to closed-house operational management. Marang *et al*. (2019) stated, water inefficiency (H_2O) during formation of ammonia can lead to an increase in litter moisture content.

The litter temperatures obtained during the fourth week ranged from 32.33–34.47 °C. Saputra *et al*. (2020) reported litter temperatures between 29.44 and 32.88 °C, indicating that the observed litter temperatures were relatively high. This is likely due to the low wind speed during the observations, ranging from 2.74–2.81 m/s in the 4th week. Vantress (2018) clarified, wind speeds in a closed-house system typically range from 3.0–4.0 m/s (600–800 fpm). The wind speed in the 1st, 2nd, and 3rd floors was 2.76 m/s. 2.81 m/s, and 2.74 m/s, respectively (Table 1). However, this approach was not effective enough



a b c d

Figure 1. Litter conditions on different floors at week 4. a. 1st floor b. 2nd floor c. 3rd floor, and d. caking conditions in the litter in the 3rd floor. The litter in the 3rd floor has a darker colour, poor condition, is denser, and forming clods.

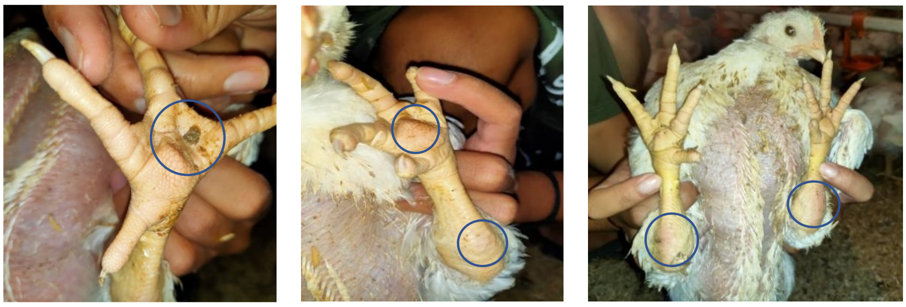


Figure 2. Broiler chickens categorized as FPD with a score of 1

to remove heat from the litter. The heat production in the 3rd floor was higher than that in the 1st and 2nd floors (Table 2), largely due to the higher cage density in the 3rd floor, which was caused by differences in broiler body weight. The average body weight of the broilers in the 3rd floor was 1.60 kg/head. compared to 1.47 kg/head in the 1st floor and 1.55 kg/head in the 2nd floor in the fourth week (Table 2). Therefore, the estimated heat production in the fourth week in the 3rd floor was 6.49% and 1.57% higher than that in the 1st and 2nd floors, respectively. Abudabos *et al.* (2013) stated, high cage density can increase heat production in broilers. Direct contact between chickens and litter causes heat conduction and increases the litter temperature. This reduces the effectiveness of heat dissipation, as both the intensity of management practices and wind speed become less effective. Mariyam *et al.* (2020) reported that the higher the cage density, the greater the heat production.

In our study, the average 4-week broiler feed consumption in the 3rd floor was higher than that in the 1st and 2nd floors, with 1.80 kg/bird/day in the 1st floor, 1.86 kg/bird/day in the 2nd floor, and 2.03 kg/bird/day in the 3rd floor. Increased feed consumption led to an increase in the amount of protein consumed, and increase of uric acid output (Table 2). The availability of uric acid, combined with water (H_2O), optimizes litter fermentation, leading to the production of CO_2, NH_3, and H_2O. Compared with those in the 1st and 2nd floors, the higher NH_3 levels in the 3rd floor at week 4 were a result of increase ammonia production from litter fermentation. Youssef *et al*. (2011), Ma'rifah *et al*. (2013), and Durmus *et al*. (2023) stated, high protein in the feed can lead to increase uric acid and ammonia production in excreta and litter. Higher protein consumption results in more undigested N, as evidenced by higher undigested protein in the feed or bypass protein in the 3rd floor by 12.84% and 8.95%, respectively, than those in the 1st and 2nd floors, thus, further increasing litter fermentation.

The percentage of litter caking in week 4 ranged from 19.24–29.53%, as presented in Table 3, which is still considered quite good and within normal limits. Caking in litter usually occurs in moist and wet areas. Sistani *et al.* (2003) and Miles *et al.* (2011) stated, the litter caking levels in broilers aged 49 days was 43%, with a litter thickness of 5–10 cm. The pH value of the 3rd floor litter was relatively higher than that of the 1st- and 2nd-floor litter because of the higher moisture and NH_3 contents of the 3rd-floor litter, which affected the pH of the litter, and resulted in poor litter conditions. Youssef *et al.* (2011) stated, moist litter tends to have a higher pH value than dry litter. As broilers age, the pH increases due to the fermentation process in the litter, producing ammonia, which is alkaline in nature. Abreu *et al*. (2011) and Durmus *et al.* (2023) reported that the increase in litter pH during the finisher phase can be caused by the accumulation of ammonia in the litter resulting in better fermentation. This finding is also consistent with the results reported by Marang *et al*. (2019), who reported that ammonia volatilization occurs well in litter with a pH > 8.

The litter in the 3rd floor is characterized by a darker color than those in the 1st and 2nd floors, indicating relatively high humidity and poor litter quality. The poorer the quality of the litter, the more active the bacteria involved in litter fermentation become. Ritz *et al*. (2004) reported that *Bacillus pasteurii* is a bacterium that plays a role in ammonia volatilization. Heitmann *et al*. (2020) reported, the bacteria commonly found in litter include coliform bacteria from the *Enterobacteriaceae* family, such as *Escherichia*, *Klebsiella*, *Enterobacter,* and *Citrobacter*. It is believed that microbial activity began to increase in the 3rd week. This is mainly due to the more ideal physical conditions of the environment and the availability of adequate substrate. As a result, the litter quality started to deteriorate in the 3rd week. Torok *et al*. (2009) and Guardia *et al*. (2011) stated, the total number of gastrointestinal bacteria is the highest during the first 3–4 weeks of the maintenance period.

Poor litter quality in the fourth week resulted in a significant increase in cases of FPD in the 3rd floor compared with those in the 1st and 2nd floors ($P<0.05$). This occurred because the 3rd floor has higher moisture content and litter ammonia levels than the 1st and 2nd floors. Shepherd and Fairchild (2010) and Wu and Hocking (2011) reported that wet litter is the main factor contributing to FPD. Ammonia acts as an irritant, and chickens' indirect contact with poor-quality litter are more prone to develop lesions on their bodies. Estevez (2002) and Durmus *et al*. (2023) reported that high levels of ammonia can cause lesions and irritation on the surface of chickens. Additionally, Kaukonen *et al*. (2016) reported that exposure to ammonia levels up to 1.77 ppm can increase FPD cases by up to 65%. An illustration of broiler chickens experiencing contact dermatitis lesions in this study is presented in Figure 2.

In addition to being influenced by litter quality, FPD cases can also be influenced by chicken body weight. In the fourth week, the body weights of broilers in the 3rd floor were significantly higher than those in the 1st and 2nd floors, with the 3rd floor averaging 1.60 kg/head, compared to 1.47 kg/head in the 1st floor and 1.55 kg/head in the 2nd floor. This increase in body weight contributed to a higher incidence of FPD. Chickens with greater body weight have more direct contact with wet litter, making them more susceptible to irritation on their body surfaces, especially on their foot pads. As body weight increases, so does the pressure and contact between the chickens and the litter, thereby elevating the risk of FPD. Costa *et al.* (2014) studied older chickens and noted that lower skin resistance and changes in foot structure contribute to FPD (Kaukonen *et al*., 2016). Taira *et al*. (2020) reported that FPD cases began to appear in chickens at 14 days of age and increased rapidly at the age of 21.

The decline in litter quality from the 3rd to 4th weeks negatively impacted body weight gain in broilers in the 3rd floor during the 4th week, with body weight 4.91% lower than that in the 1st floor and 13.71% lower than that in the 2nd floor. Research by Beker *et al*. (2004) revealed that exposure to ammonia at concentrations up to 60 ppm can reduce feed intake by 4.4%. Similarly, Miles *et al.* (2004) found that ammonia concentrations of 50–70 ppm can reduce body weight gain by 6–9%. While the ammonia levels in our study were not as high as those reported in the aforementioned studies, we observed a significant reduction in feed consumption on floors with higher microclimatic ammonia levels. In the 4th week, the feed consumption in the 3rd floor was 12.94% lower than that in the 1st floor and 12.04% lower than that in the 2nd floor, despite the cumulative feed intake since the start of rearing being higher in the 3rd floor. Yahav (2004), Miles *et al*. (2004), Soliman *et al*. (2017) and Javed *et al*. (2021) reported, poor quality of the litter leads to higher ammonia concentrations, which, in turn, reduces feed consumption negatively affecting body weight gain and overall performance.

Our study concludes that during the starter period, there was no significant change in litter quality, including water content, temperature, NH_3 content, pH, and litter caking. This is because broilers are still young, and the ability of the litter material to retain moisture remains effective. The management of the litter, including the addition of husks, is more efficient during the starter period, ensuring that the quality of the litter is not yet saturated and remains relatively good. However, during the finisher period, there was a significant decline in litter quality, including increased water content, temperature, NH_3 content, and percentage of caking. This occurred because litter management became less effective due to increased cage density. The saturation of litter, coupled with high moisture content and increased excreta output in the form of uric acid during the finisher period, initiated a litter fermentation process, that further reduced litter quality. The decline in litter quality in the 3rd floor was more pronounced due to higher excreta production and better growth rates than those in the 1st and 2nd floors. Therefore, specific operational adjustments to the control panel and distinct litter management practices for each cage floor are necessary to maintain litter quality.

CONCLUSION

The microclimatic conditions and air quality of the 3rd floor were generally superior to those of the lower floors over the 4-week rearing period. However, the litter quality was inferior. Each floor needs to be carefully managed according to its conditions.

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