Al-Muthanna J. For Agric Sci **Online ISSN:2572-5149**
Print ISSN: 2226-4086
Vol. 12 , Issue 2. **2025**

https://muthjas.mu.edu.iq/ http://doi.org/10.52113/mjas04/12.2/23

Impact of Housing Factors on Broiler Litter Quality and air Contaminants

Ahmed Akbar Ali[1] Samer B. Salman AL-Badri[1] Ikram Hussain Abdullah[2]

[1]: Department of Agricultural Machines and Equipment, College of Agricultural Engineering Sciences, University of Baghdad, Baghdad, Iraq. [2]: Poultry Research Station - Iraqi National Board of Agri. Research.

*a part of PhD. Thesis of the first author
Correspondent author: Samer B. Salman AL-Badri.
Email: samir.albadri@coagri.uobaghdad.edu.iq

Abstract

A study was conducted in a broiler house belonged to Poultry research station - national Board of Agri. Research Iraq -Baghdad. The purpose of the study was to investigate how the rearing system affects the litter chemical components, hence how these elements impact the air pollutants in the poultry house especially ammonia, (particulate Matter) PM10 and PM2.5 µm. The litter chemical components include Ph, dry matter, moisture, ash, organic matter, nitrogen and crude protein. 608 birds were distributed into 16 pens inside the poultry house under varying conditions: first Litter/padding deep 5 vs 7 cm. second, spatial distribution, or in other word bird location near air inlet vs. exhaust outlet, third was stocking density (7 birds /m^2 vs. 12 birds/ m^2). The Amonia gas was quantified by the multiple gas monitoring detector S360 along with BENETECH-GM8806-Ammona-Gas-Detector as back up device.

The pm 10 and 2.5 µm were quantified using multiple gas monitoring and detector S360.THC-4 temperature and humidity data logger was used to log the data. The findings demonstrated that not all the litter's chemical constituents were impacted. The only factor that had an impact on the parameters of dry matter, moisture, ash, and organic matter was the stocking density. The results also showed that the ammonia level was not detectable during all 5weeks of age. The pm10 and 2.5 µm were very high in the beginning of rearing period with lower rates in between because of using gaseous brooders in the beginning of the rearing period and later on due to the high levels of dust particles resulting from the ground feed that was provided to the birds more than once daily , because the birds grow in age and became larger in size hence the mechanism of its wings interacting with the litter and feed became also stronger during the last stages of rearing.

Key words: **Ammonia, Bedding Thickness, Birds Spatial Location, Pm10and 2.5 µm, Stocking Density.**

1.Introduction

Management of the miniclimate in Poultry houses represent a challenge to the growers. because most of rearing procedures in broiler houses aims to increase income and push the limit of stocking density to the far most, on the condition of balancing with welfare of the flock [1]. The litter is considered a very important parameter in the equation of handling with the microclimate inside the house, because this medium is interactive with the birds. the litter absorb the exert of the birds and controls emissions inside the house. The litter interacts continuously with the environment throughout the rearing period; thus, it's physical and chemical properties is affected, hence the microclimate quality surrounding the birds is affected too [2] [3]. among the factors affecting litter quality is how deep it is. the thickness of the litter impacts the trait of absorption of moisture [4] . the stocking density also affects the litter in terms of its quality and quantity of constituents present in it [5] [6]. special distribution is affected by the performance of the ventilation which in turn affects the litter moisture (quantity) thus performance of the birds could be heterogenous if the microclimate wasn't uniform throughout the broiler house [7].

This study aims to investigate litter thickness, stocking density and birds' distribution inside the house on chemical characteristics of the litter such as: Ph, dry matter, moisture, ash, organic matter, nitrogen, and crude protein.

2.Materials and Methods

A study was conducted during the period of April 1st to May 5th, 2025, at poultry research station, Iraqi national board of Agricultural research, in Abu Ghraib district – Baghdad Iraq. The figure (1) shows the broiler house. A 608 bird were used in the experiment distributed into 16 pens, each measuring 4 m². The ventilation system in the house was cross section design in which the air moves laterally. Litter thickness of 5 and 7 cm, stocking density of 28 and 48 birds per pen, and the distribution of birds within the house at position 1 (the intake air openings) and position 2 (the outlet openings on the exhaust fan side) were the factors under investigation. The BENETECH-GM8806-Ammona-Gas-Detector figure (3) and the multiple gas monitoring detector S360 figure (2) were used to quantify the ammonia gas. The pm 10 and 2.5 µm were measured using (multiple gas monitoring and detector S360 device). The contaminants were measured in the front and back of the house in the microclimate symbolled as A and B in figure (1). The Litter samples were collected at the end of the rearing period then laboratorial analysed.

Then according to kjeldal method as stated in [8] the total protein was measured by:

$$N = \frac{1.401 * (Vsample - Vblank) * N\ acid * (\frac{Vdigest}{Vdistelld})}{sample\ weight} \ldots\ldots.(1)$$

Where: Vsample: Volume of standard acid used for titration of the sample(mL)
Vblank: volume of acid used for blank (mL)
1.401: atomic weight of nitrogen (g.mol-1)
V_{digest}: total volume of the digested sample (mL)
$V_{distelled}$: total volume of distilled sample (mL)

Then N%= N*6.25………. (2)

Ash was measured according to [9], [10]. organic matter, Carbone, ph. was quantified according to [11] and [10].

(multiple gas monitoring detector device of S360) working is based on air continuous sucking pump and adopted for quantifying Ammonia gas, along with (BENETECH-GM8806-Ammona-Gas-Detector device) was used as a backup device as in Figure (2) and (3) accordingly.THC-4 temperature and humidity data logger device as in figure (4). The Statistical analysis used was complete randomized design CRD by SAS programme. LSD was used for comparison among the means P<0.005.

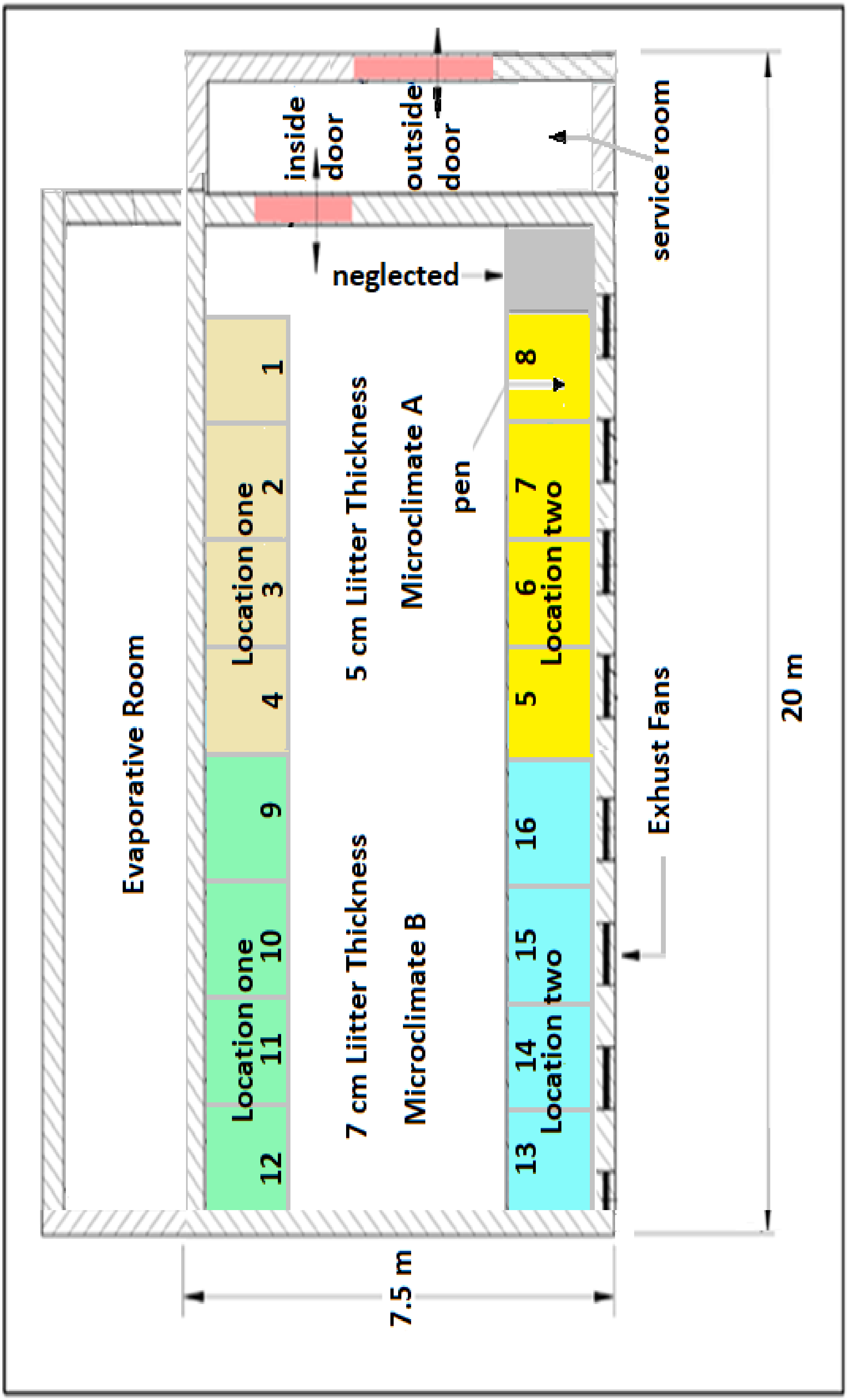


Figure (1) the design of the broiler house

Figure (2) using the multiple gas monitoring detector of S 360

Figure (3) BENETECH-GM8806 Ammonia-Gas-Detector

Figure (4) THC-4 temperature and humidity data logger

3.Results and Discussion

3.1 Special Distribution Impact on Litter Physiochemical Ssubstances

The results in table (1) explain how the elements in the litter affect the studied traits. For example, the characteristics under study were unaffected by the location factor, in other words, the litter substance groups were comparable in their averages. That leads us to assume that the environment on either side of the house didn't have effect on physiochemical substances that all together constitutes the litter, this is in consistent with [12] who said the temperature and humidity if were spatially heterogenous in the house the litter will perform differently , in accordance, in our study temperature and humidity levels were similar on both sides as seen in figure (5)and(6). For instance, figure (5) shows the relation between Temperature and humidity during the production period of 5 weeks and the *covariance* of is related to figure (1) that shows were the pens are present in which side of the house along with the specified litter thickness.

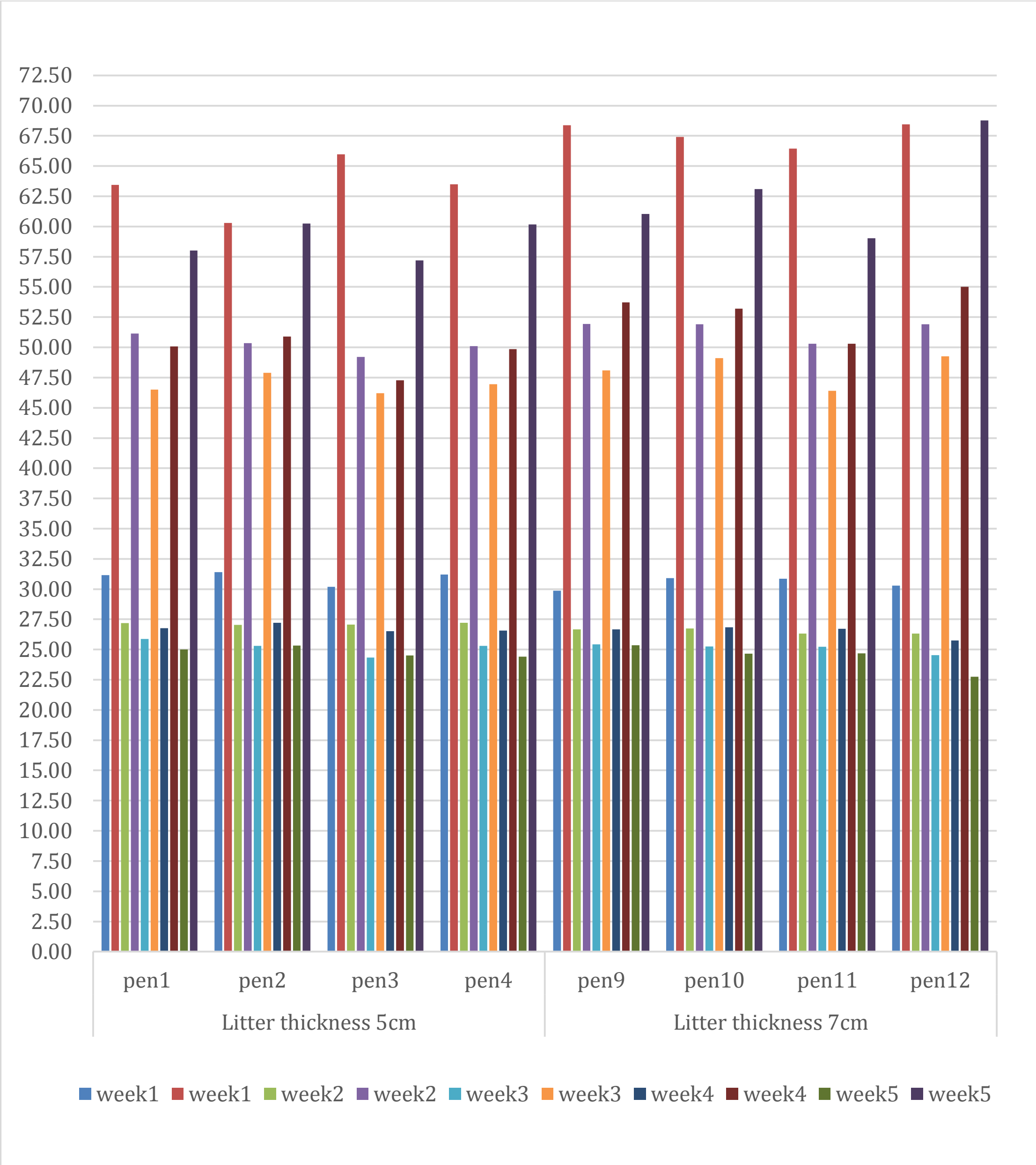


Figure (5) pattern of Temperature and humidity distribution in the first location of A on the side of air inlets openings T: temperature H: relative humidity

Whereby temperature levels didn't exceed 31°C in all weeks of Age of the birds (WOA). Temperature had more uniform pattern in the house in comparison with Relative humidity, which had a diverted percentage from good levels in the early and last phases of production along with lower percentage in week 2,3, and 4 of birds' age. That's due to the diverse climate the house encountered during April in 2025 in Baghdad. The beginning of the month was cold, so we turned on the Brooders, resulting in increasing temperature along with decreasing relative humidity to the point we needed to add water on the empty spaces on the ground, afterward in (week of age) WOA2, WOA3, WOA4 the climate began to be warmth thus we shifted to the maximum ventilation providing turning off the brooders. But at the end in WOA5 the climate was turning into hot, hence the birds needed evaporation cooling to retain the neutral climate zone, leading to increase in relative humidity to a suitable level.

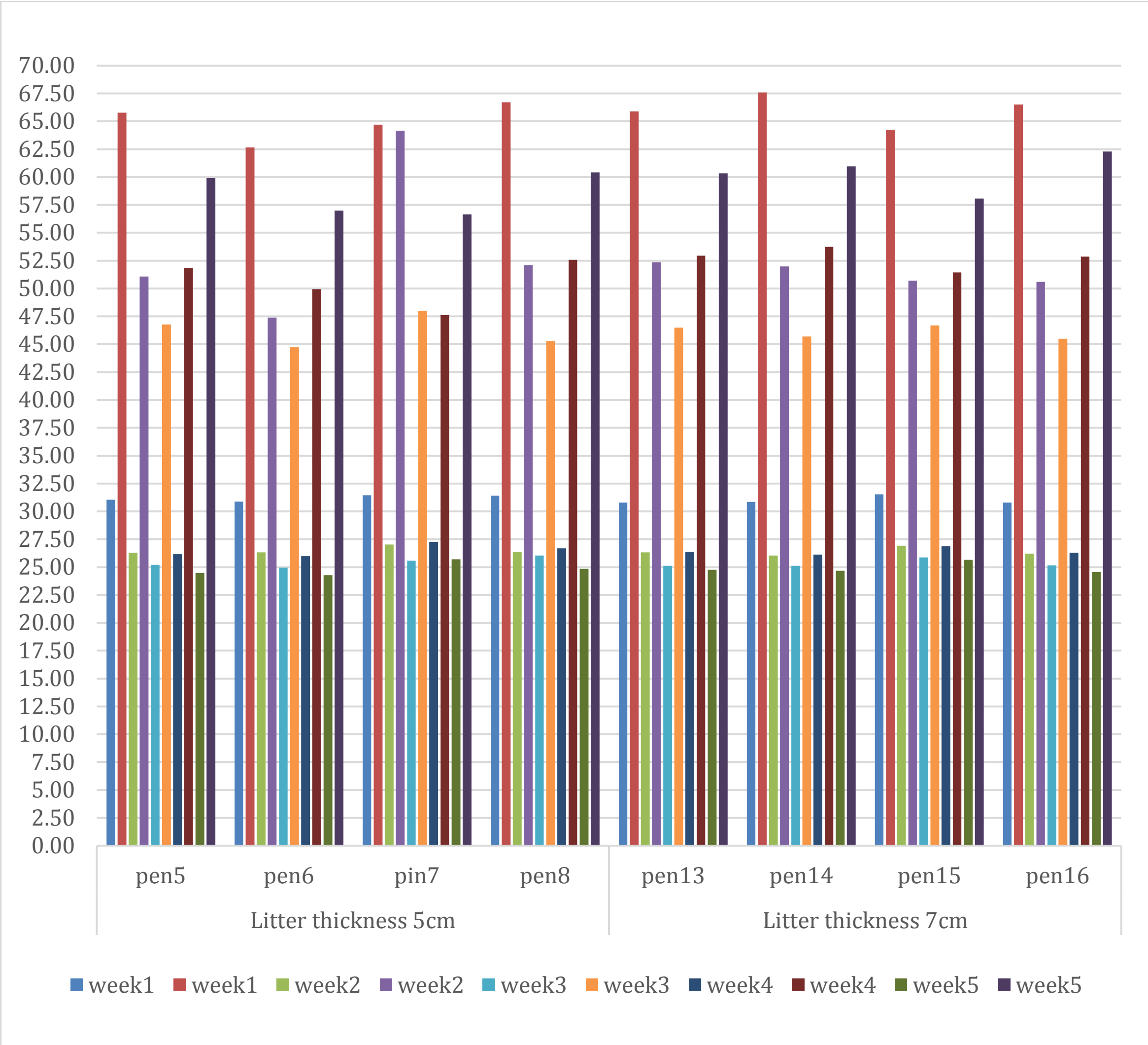


Figure (6) pattern of Temperature and humidity distribution in the second location B on the side of exhaust fans. T: temperature H: relative humidity

So, what is recommended is to keep relative humidity on the 50-70% level during all the production period, nevertheless it was not uniform, but stable throughout the pens during individual WOA of the birds. Put differently, all the pens in WOA1 had a same percentage of relative humidity, but the pens' relative humidity levels in WOA1 in comparison to WOA2 didn't appear to be the same. [13] stated that it’s best to keep the relative humidity above 50% to have a concentration of moister 30-35 % in litter, and we kept it that way in our study. [14] also said water activity as an environment factor which is impacted by relative humidity, whenever the later was uniform the effect of the resulting water activity will be uniform on the litter. Figures 5 and 6 show that they perform similarly each week, that is, when you compare WOA1 at location 1 with WOA1 at location 2, they look very similar. However, when you compare WOA1 at location 1 with WOA2 at location 2, or even with location 1 itself, they don't look similar because the rearing period began in January 2025, and it was quite cold, so we had to use gas brooders. , afterwords in WOA2 the weather started to get worm so we turned down the brooders, and used maximum ventilation until the end of the rearing period, then we shifted to evaporation cooling due to the high levels of temperature.

3.2 Litter/padding Thickness impact on Litter Physiochemical substances

The effect of Litter deep, showed no impact on the studied traits, in other words the levels of Litter thickness had no effect on the group of substances and this is in consistence with [15] whom indicated there were no differences in the depths (5.08, 6.35 and 7.62 cm) on the Litter traits , also the results were in consistence with [16]

3.3 Stocking density Impact on Litter Physiochemical substances

Table (1) shows that Stocking density didn’t have an impact on Ph, Nitrogen, and crude protein. On the other hand, The Stocking density had a highly significant impact on other substances such as Dry Matter, Moisture, Ash, and Organic Matter. The dry mater content was higher in the lower density of 28bird /pen (7 bird $.m^{-2}$) of 71.98 in comparison with 48 bird/ pen (12 bird $.m^{-2}$). since the less density produces less manure, it remains drier and more stable leading to higher dry matter content.

Table (1) Impact of Location of the Bird, Stocking Density and Litter Thickness on the Components of The Litter

Factors	**Levels**	**Litter Substances (Traits)**						
		Ph	**Dry Matter**	**Moisture**	**Ash**	**Organic Matter**	**Nitrogen**	**Crude Protein**
Location	1	8.37 [a]	68.52 [a]	31.55 [a]	10.52 [a]	89.47 [a]	3.11 [a]	19.47 [a]
	2	8.39 [a]	69.37 [a]	30.62 [a]	10.16 [a]	89.83 [a]	2.91 [a]	18.226 [a]
	L.S. D	0.66	3.92	3.92	1.88	1.88	0.81	5.06
	Pr<0.05	**N. S**	**N. S**	**N. S**	**N. S**	**N. S**	**N. S**	**N. S**
Litter Deep	5 cm	8.09 [a]	67.53 [a]	32.46 [a]	10.75 [a]	89.24 [a]	2.92 [a]	18.29 [a]
	7 cm	8.67 [a]	70.36 [a]	29.71 [a]	9.93 [a]	90.06 [a]	3.10 [a]	19.40 [a]
	L.S. D	0.66	3.92	3.92	1.88	1.88	0.81	5.06
	Pr<0.05	**N. S**	**N. S**	**N. S**	**N. S**	**N. S**	**N. S**	**N. S**
Stocking Density	28	8.47 [a]	71.98 [a]	28.08 [b]	9.07 [b]	90.92 [a]	2.79 [a]	17.43 [a]
	48	8.29 [a]	65.91 [b]	34.08 [a]	11.61 [a]	88.38 [b]	3.24 [a]	20.26 [a]
	L.S. D	0.66	3.92	3.92	1.88	1.88	0.81	5.06
	Pr<0.05	**N. S**	**	**	**	**	**N. S**	**N. S**

The same letters indicate a similarity in means N. S = not significant * = significant ** = highly significant

In addition, with less bird density a better distribution of birds occurs leading to less competition on drinkers thus less water spillage on the litter for the less density recorded 28.08% in comparison to the high density recorded 34.08%.

Table (1) shows the level of ash was higher in the SD of 48 bird /pen recording highly significance difference of 11.61% in comparison with the lowest SD of 28 bird/pen recording 9.07%, while the organic matter increased highly significantly in the lowest SD of 28 bird /pen recording 90.92% in comparison with higher SD of 48 bird/pen recording 88.38%. The reason for that can be simplified in the fact that Ash is the leftover of litter burning , it includes minerals such as P and Ca along with uric acid and urea so more birds means more feed intake leading to more excreta that is rich in minerals and salts ,Higher SD produce more moisture [17], [18]and [19]. Hence it will help in retention of Ash this is in consistence with [20] whom said higher moisture leads to higher inorganic compounds like ash.

3.3 Impact of Stocking Density on Birds Performance

Since stocking density had influence on some components of the litter, it’s useful to know the effect of stocking density on broiler performance. Table (2) shows the effect of Impact of Stocking Density on Birds Performance. It’s obvious that the lowest stocking density (LSD) of 28 bird /pen had the significant advantage of cumulated FCR ratio by recording the lowest FCR ratio of 1.29 gram feed/ gram gain weight in comparison with the (higher stocking density (HSD) of 48 bird/ pen recording 132 gram feed/ gram weight gain [21]and [22], also [23] said that the group recording the lowest FCR ratio is the best performing group. In table (2) we conclude that the same goes on in favour of the (LSD) for the rest indicators of the performance whereby SD of 28 bird /pen recorded the significant larger body weight of 2352.21 gm live weight in comparison with SD of 48 bird/pen recorded 2296.56 gm live weight. SD of 28 bird /pen consumed less cumulative feed intake of 3172.44 gm of feed in comparison with SD of 48 bird/pen recorded 3141.42 gm of feed. Table (2) elicit that SD of 28 bird /pen recorded significantly better cumulative weight gain of 2307.01gram in comparison with SD of 48 bird/pen of 2253.94. To address the cause why the lowest stocking density did record the best performance is easiness of moving around, thus reaching to the water and feed resources freely, this is in consistence with [24].

Table (2) Impact of Stocking Density on Birds Performance

Traits	Stocking Density	Weeks of Age					Cumulation
		1	2	3	4	5	
Body Weight (gm)	28	204.35 [a]	568.04 [a]	1092.33 [a]	1656.05 [a]	2352.21 [a]	--
	48	202.27 [a]	569.99 [a]	1085.36 [a]	1634.20 [a]	2296.56 [b]	--
	L.S. D	5.41	20.31	23	28.17	50.29	--
	Pr<0.05	N. S	N. S	N. S	N. S	*	--
Feed Consumption (gm)	28	160.74 [b]	424.17 [a]	644.50 [a]	828.51 [a]	1114.52 [a]	3172.44 [a]
	48	169.95 [a]	431.30 [a]	654.76 [a]	825.55 [a]	1059.83 [a]	3141.42 [a]
	L.S. D	8.46	18.32	14.04	19.78	87.62	85.83
	Pr<0.05	*	N. S	N. S	N. S	N. S	N. S
Weight Increase	28	159.35 [a]	363.68[a]	524.29[a]	563.71 [a]	696.16 [a]	2307.01 [a]
	48	159.64 [a]	367.72[a]	515.37[a]	548.83 [a]	662.36 [a]	2253.94 [b]
	L.S. D	4.63	19.27	10.42	20.299	54.79	51.03
	Pr<0.05	N. S	N. S	N. S	N. S	N. S	*
Feed Conversion Ratio	28	1.01 [b]	1.16 [a]	1.23 [b]	1.47 [b]	1.60 [a]	1.29 [b]
	48	1.06 [a]	1.17 [a]	1.27 [a]	1.50 [a]	1.60 [a]	1.32 [a]
	L.S. D	0.05	0.03	0.03	0.03	0.02	0.01
	Pr<0.05	*	N. S	*	*	N. S	**

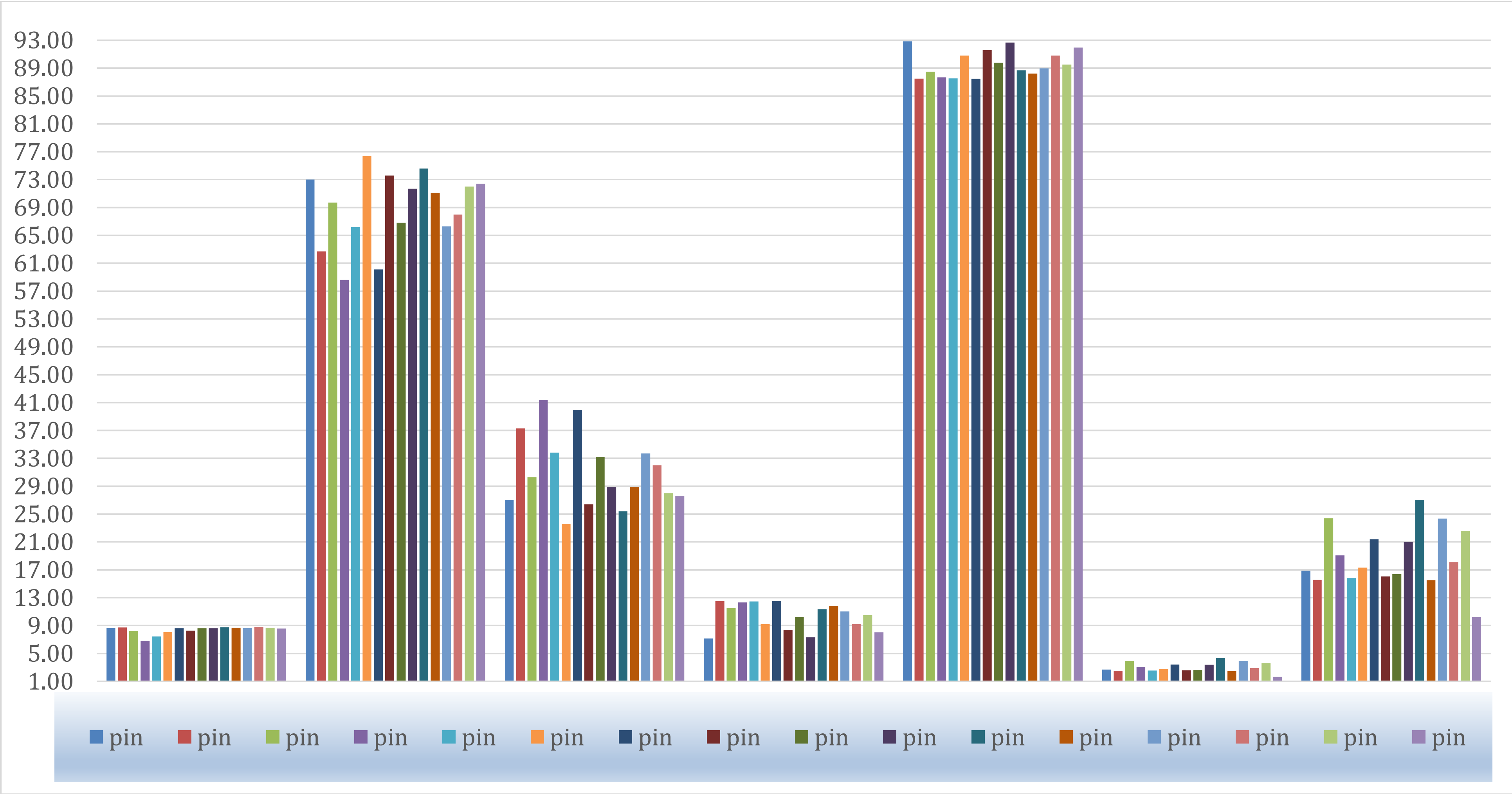
The same letters indicate a similarity in means   N. S = not significant   * = significant   ** = highly significant

Figure (7) is illustrating the Laboratory analysis of the litter indicating the percentage components of the substances constituting the Litter.

When we go through Figure (7), we find that Ph didn't exceed 9 in all the pens. The highest recorded PH was 8,77 in pen 11. PH is not the only reason to release ammonia from the litter. Temperature, humidity, ventilation rate and air velocity are all detrimental too [25] and [26]. [26] also said that microbial growth in chicken manure is optimal between 40-60 % and ammonia emissions increases, but at levels above and beyond that on the contrary ammonia emissions decreases.in our study when you look at figure (5) only two pens/nests exceeded litter moisture content of 37% ,meaning that 37% moisture content is detrimental in prohibiting ammonia emission inside the house. Water activity on the other hand referred to as A_w is an indicator of water availability for microorganism, so it's a better descriptive parameter for microbial growth in comparison with moisture content, high dry matter content in the litter decreases the available water thus decreases microbial activity [26]. In our study when looking to figure (5), The litter that was made of saw chips was of high content of dry matter of average 75%. The data in figure (5) indicates that dry matter has the biggest percentage in comparison with other components. dry matter is composed of ash+ organic matter [11] so higher dry matter leads to less ammonia emissions, that's corresponds with our data in this experiment whereby high percentage of dry matter was recorded as seen in figure (5).

as for crude protein which is simply nitrogen multiplied by a constant factor CP=N*6.25 [8] it tells us how much protein is there originally in the diet but not all of it converted to ammonia in other words it's the lever that we can adjust nutritionally the N concentration in the litter that could be transformed to ammonia. N levels below (3% of DM) were recorded in our study along with low moisture average of 33% and considerably good PH level.

birds consume CP in the feed then exerts ammonia10% plus nitrogen into the litter as uric acid80% and urea5% microbes in the litter breaks down these into +NH4 depending on PH moisture content, temperature and dry matter content, a portion of it converted to ammonia gas, thus this process reduces the concentration of N in the litter [27] ,that's corresponds with our findings in recording ready percentage of N to be transformed into NH3 gas due to using saw chips with good thickness of 5 and 7 cm .



Figure(7) the phisiochemical components of the litter

3.4 Particulte Matter2.5µm

What is observed from figure (6) are the following:

1) during WOA1 PM2.5 µm is the highst at the back of the house compared to the front.

2) during WOA1and WOA2 both levels of PM2.5 µm at the back and front side droped remarkbly.

3) during WOA4 the levels of PM2.5 µm rise again also the back and front side are both closely identical.

4) during WOA5 the front of the house recorded the highst concetrations of PM2.5 µm levels recorded across all the weeks of ages.

[28] said that aerosol is used as synonym for particulate matter. They all classified as dust levels. It was above the recommended levels especially during the last week it recorded 35 m this was in consistence with [29] whom said: during the end of rearing period of broiler PM 2.5 µm goes up.

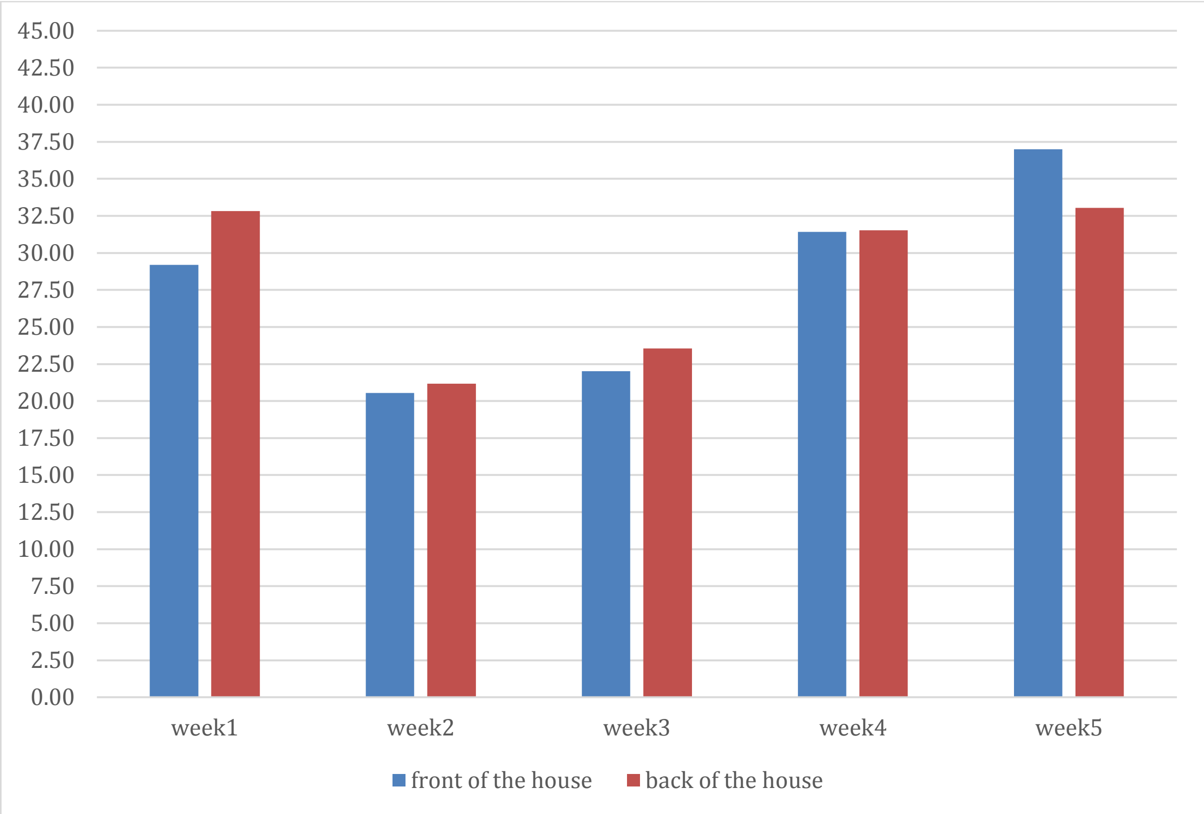


Figure (6) levels of particulate matter of 2.5µm

The results of the study is explained by the facts that the concetrations of 2.5 µm is the highest concentration in the rear side of the house during production period, except for the last week as in figure (6), this is in consistence with [30] whom mentioned there are special and temporal variations in particulate matter distributions. He stated that it accumulates in the locations with poor ventilation. He also stated that Carbone levels are linked with raising in 2.5 µm because it represent large amounts of C.

Carbone is generated mainly in the poultry house from using gaseous brooders especialy in cold seasons.Thats what has been through during the first week of production, the tempretures went down thus we nedded to operate the brooders . as for why the levels of pm 2.5 went up during the last week was explaind it in a way that the birds grew in age and size, so they interact more with the litter by their wings, more over the feed was in ground format and was provided more than onece on daily basis.This is in consistanc with [29] [31].

3.5 Particulate Matter 10µm

When looking to figure (7) we can drive the following conclusions:

1) During WOA 1 the PM10 µm levels at the back of the house had a higher level in comparison with the front side of the house.
2) During WOA2 and WOA3 the PM10 at both sides in the front and back of the house decreased remarkably.
3) During WOA4 the PM10 µm levels at both sides were closely identical
4) During WOA5 the PM10 µm levels at the back was slightly higher.

to break this out we should look again to Figure (7).it reveals that particulate matter 10µm followed a pattern like 2.5 µm. whereby in the beginning of the rearing period was high due to the working of gaseous brooders that consumes fossil fuel. Soot and Carbon dioxide is the results of incomplete burning due to that reason particulate matter was high in the first week. in the following weeks, the environment became warmer thus the brooders were turned off keeping only continuous ventilation leading to more moderate concentrations during the middle period of the rearing. But at the end of the production namely last week the cooling evaporation system was turned on, still a high level of particulate matter was recorded. the reason could be explained in simple way, when the birds grow older and larger in size demanding more feed that sometimes placed twice daily to the birds moreover the feed was in the form of ground materials not in pellet. also, when the birds grow larger the interaction mechanism between the wings and litter also grew , this is in consistence with [29] [31]. [32]and [33] showed that when birds grow in age the levels of fine particulate matter rise because of increased activity and feather production.

The threshold of particulate matter 10µm didn't excess 41.44 ppm, it was during the last week in the rear section of the house nevertheless stayed under the allowed levels > 150 ppm [29] .

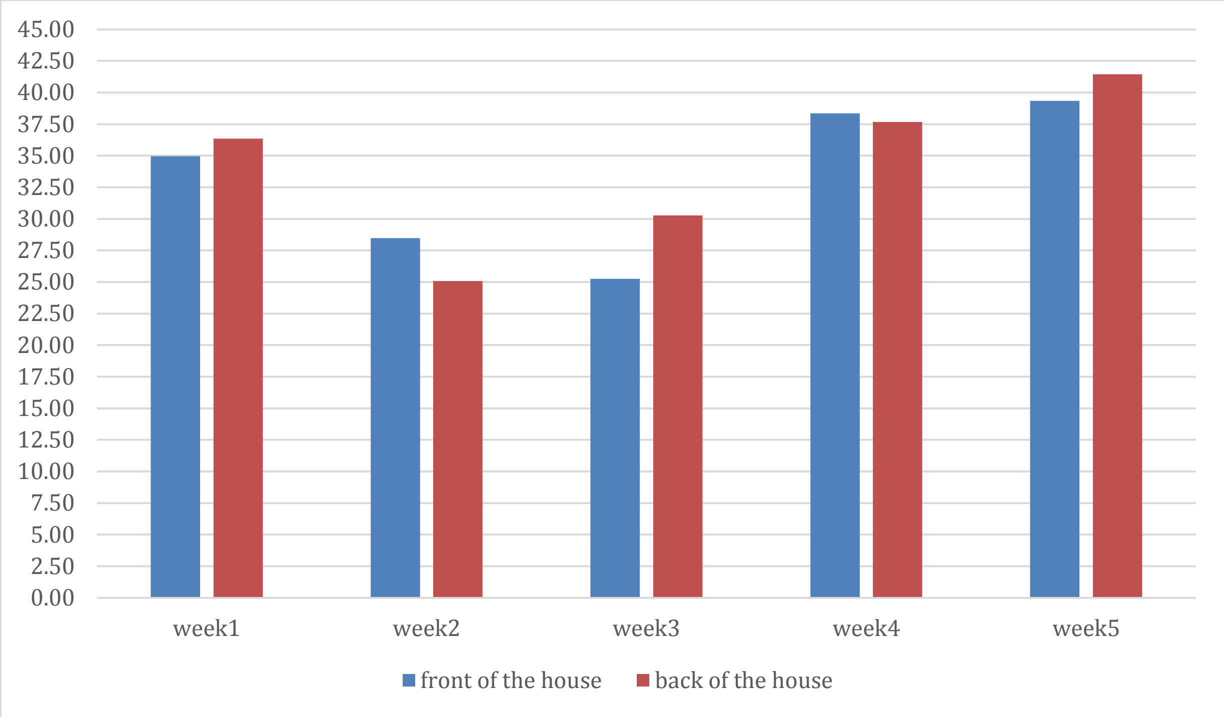


Figure (7) levels of particulate matter of 10µm

3.6 Ammonia

The levels of this gas were so low that the equipment didn't record any. [34] stated that the contaminants problem is a winter issue and stayed zero during all the rearing periods ,He stated the reason is due to the moisture in the litter that stayed under 55% in our findings the moisture content was much less, moreover the thickness of the litter helped in drying the droppings thus remained as nitrogen in the litter , nevertheless the humidity didn't allowed to release it into the air this is in consistence with [35]. [31] also mentioned that ammonia levels remain undetectable during the production period of 8 weeks. [36] indicted that ammonia levels remain undetectable during the production period of 6 weeks. [26] When talking about NH3 both quantity and composition of droppings are of interest.

Ammonia is the product of decomposition of bedding material, due to bacterial activity on the condition that temperature being higher than 25°C and moisture higher than 40%, other than that it remains in the form of $^{+}$ NH4 [37]. [38] claimed that the ammonia level was undetectable in his study because of the small size of the birds during the first two weeks and the small number of herds raised.

[39] show that because of the continuous ventilation method used, the concentration of ammonia inside the house is lower than the amounts released outside through the exhaust fans. [40] stated that perfect litter condition to not releasing ammonia is the PH of the bedding 8-10 ppm.

[41] indicated that the key to minimize ammonia formation specially in cold weather is not by ventilation but rather moisture control. [42] Said moisture can rise in the poultry house to 100% after 15 minutes of shutting down the exhaust fans for the 5 weeks of age of birds.

Conclusions

- Litter thickness and Spatial distribution of birds did not have impact on physiochemical substances within the litter.
- Stocking density only had an impact on certain litter substances, namely: moisture, dry matter, ash, and organic matter. only
- Stocking density had no impact on the rest parameters of the substances constituting the bedding/litter substances.
- The format of the feed given to the birds and the product of the gaseous brooders influenced the levels of Particulate Matter 10 and 2.5 µm.
- Ammonia levels were undetectable during the production period.

References

[1] A. M. Abudabos, E. Samara, E. O. Hussein, R. M. Al-Atiyat and Al-Haidary, "Influence of stocking density on welfare indices of broilers. Italian Journal of Animal Science," vol 12, no. 2, p. 35, 2013.

[2] T. U. Extension, "Managing poultry litter to improve air quality and animal welfare (Publication W1135)," university of Tennssee, Tennssee-USA, 2023.

[3] Y. Liang and G. T. Tabler, "Litter management for broiler production (Publication FSA1098)," University of Arkansas , Arkansas, 2023.

[4] J. M. Cohuo-Colli, J. Salinas-Ruíz, A. S. Hernández-Cázares, J. V. Hidalgo-Contreras, V. H. Brito-Damián and J. Velasco-Velasco, "Effect of litter density and foot health program on ammonia emissions in broiler chickens," *Journal of Applied Poultry Research,* vol. 72, no. 2, pp. 198-205, 2018.

[5]

[6] D. Rohmadi and S. Harimurti, "Effects of stocking density and litter type on litter quality of native chicken. : , No. IOP Publishing.," in *Earth and Environmental ScienceIn IOP Conference Series. The 8th International Seminar on Tropical Animal Production 23–25 September*, Yogyakarta, Indonesia, 2019.

[7] C. T. Mou, M. Czarick III and B. D. Fairchild, "Evaluation of the effects of maintaining a moderate humidity (50–60%) and increased air movement on litter moisture and footpad health in a commercial broiler house," *Journal of Applied Poultry Research,* vol. 34, no. 1, p. 100476, 2025.

[8] AOAC, "Association of official analytical chemists," official methods of analysis 19 th. Ed., Washington, D.C., U.S.A., 2019.

[9] N. Thiex, L. Novotny and A. Crawford, "Determination of ash in animal feed: AOAC official method 942.05 revisited," *Journal of AOAC international,* vol. 95, no. 5, pp. 1392-1397, 2012.

[10] AOAC, " Association of official analytical chemists, Official Methods Of Analysis 22nd. Ed.," Washington, D.C., U.S.A, 2023.

[11] T. Maruthamuthu, S. Karuppusamy, R. Veeramalai, M. Nagarajan, P. Manika Ragavan, M. Santiago, B. Nallathambi, A. Dharmalingam, K. Radhakrishnan, A. Ramasamy and Ramasamy, "Physicochemical Characterization of Broiler Poultry Litter from Commercial Broiler Poultry Operation in Semiarid Tropics of India," *Agriculture,* vol. 14, no. 10, p. 1708, 2024.

[12] P. P. Ferraz, . G. S. Ferraz, L. Schiassi, V. B. Nogueira, M. Barbari and F. A. Damasceno, "Spatial variability of litter temperature, relative air humidity and skin temperature of chicks in a commercial broiler house," *Agronomy Research,* vol. 17, pp. 408-417, 2019.

[13] L. B. Reece FN, "Heat and moisture production of broiler chickens during brooding," *Poultry Science,* vol. 61, no. 4, pp. 661-666, 1982.

[14] M. W. Dunlop, J. McAuley, P. J. Blackall and R. M. Stuetz, "Water activity of poultry litter: Relationship to moisture content during a grow-out," *Journal of Environmental Management,* vol. 172, pp. 201-206, 2016.

[15] P. K. Malakar, S. K. Fouzder , M. Ahmed and M. A. Wahid , "Broiler performance on different types of litter at different depths in summer," *Bangladesh Veterinarian,* vol. 19, no. 1, pp. 34-38, 2002.

[16] H. Demirulus, "The effect of litter type and litter thickness on broiler carcass traits," *International Journal of Poultry Science,* vol. 5, no. 7, pp. 670-672, 2006.

[17] A. McKeith, M. Loper and K. J. Tarrant, "Research Note: Stocking density effects on production qualities of broilers raised without the use of antibiotics,"

Poultry Science, vol. 99, no. 2, pp. 698-701, 2020.

[18] R. D. Marewad, M. V. Dhumal and M. G. Nikam, "Studies on different stocking densities on performance and economics of broiler chicken," *International Journal of Agricultural Science and Research,* vol. 6, no. 6, pp. 359-70, 2016.

[19] H. K. Kang , S. B. Park, S. H. Kim and C. H. Kim, "Effects of stock density on the laying performance, blood parameter, corticosterone, litter quality, gas emission and bone mineral density of laying hens in floor pens," *Poultry Science,* vol. 95, no. 12, pp. 2764-2770, 2016.

[20] S. Katuwal, N. S. Rafsan, A. J. Ashworth and P. Kolar, "Poultry litter physiochemical characterization based on production conditions for circular systems," *BioResources,* vol. 18, no. 2, p. 3961, 2023.

[21] K. Nutan, P. Ramesh, S. R. Pal, S. A. Kumar and U. Gaurav, "Effect of Stocking Density on Feed Efficiency of Caged Broilers under Hot Climatic Conditions," *Archives of Current Research International,* vol. 25, no. 2, pp. 1-5, 2025.

[22] K. K. Thema, C. M. Mnisi and V. Mlambo, "Stocking density-induced changes in growth performance, blood parameters, meat quality traits, and welfare of broiler chickens reared under semi-arid subtropical conditions," *PLoS One,* vol. 17, no. 10, p. e0275811, 2022.

[23] A. S. El-Deen, F. Abdel-Azeem and A. Al-Gamal, "Effect of two housing systems on productive performance and some physiological traits of broiler chickens reared in enclosed houses. ," *Egyptian Journal of Applied Science,* vol. 35, no. 1, pp. 1-12, 2020.

[24] A. A. Abdelgaber, A. A. Mohammed, U. T. Mahmoud and M. H. Darwish, "EFFECT OF STOCKING DENSITY ON BROILERS BEHAVIOUR AND WELFARE INDICES.," *Assiut Veterinary Medical Journal,* vol. 179, no. 69, pp. 1-13, 2023.

[25] A. A. Swelum, M. T. El-Saadony, M. E. Abd El-Hack, M. A. Ghanima, M. Shukry, R. A. Alhotan, E. O. Hussein, G. M. Suliman, H. Ba-Awadh, A. A. Ammari and A. E. Taha, "mmonia emissions in poultry houses and microbial nitrification as a promising reduction strategy. ,," *Science of The Total Environment,* vol. 10, no. 781, p. 146978, 2021..

[26] P. G. Koerkamp, "Review on emissions of ammonia from housing systems for laying hens in relation to sources, processes, building design and manure handling," *Journal of Agricultural Engineering Research,* vol. 59, no. 2, pp. 73-87, 1994.

[27] Amit, "Poultry Punch," 11 November 2019. [Online]. Available: https://thepoultrypunch.com/2019/11/management-of-ammonia-emission-in-poultry-house/?utm_source=chatgpt.com. [Accessed 10 6 2025].

[28] M. Cambra López, Control of particulate matter emissions from poultry and pig houses., Dutch Ministry of Agriculture, Nature and Food Quality. , 2010.

[29] R. B. Bist and L. Chai, "Advanced strategies for mitigating particulate matter generations in poultry houses.," *Applied Sciences,* vol. 12, no. 22, p. 11323, 2022.

[30] S. Publication, "Particulate matter in poultry houses/farm poses significant threat to the respiratory health of the birds.," SR Publication , 2024. [Online]. Available: https://www.srpublication.com/particulate-matter-pm-in-poultry-houses-farm-poses-significant-threat-to-the-respiratory-health-of-the-birds/?utm_source=chatgpt.com. [Accessed 25 7 2025].

[31] R. B. Bist, X. Yang, S. Subedi, M. K. Sharma, A. K. Singh, C. W. Ritz, W. K. Kim and L. Chai, "Temporal variations of air quality in cage-free experimental pullet houses," *Poultry,* vol. 2, no. 2, pp. 320-333, 2023.

[32] K. Wang, D. Shen, P. Dai and C. Li, "Particulate matter in poultry house on poultry respiratory disease: a systematic review," *Poultry Science,* vol. 102, no. 4, p. 102556, 2023.

[33] P. Lolek, "Air quality in the broiler house: The profit-making balance. PoultryScales," Bat Scales, 4 September 2025. [Online]. Available: https://poultryscales.com/academy/air-quality-in-the-broiler-house-the-profit-making-balance?utm_source=chatgpt.com. [Accessed 4 8 2025].

[34] G. L, Z. B, Y. Jia, H. F and C. W, “Mitigation strategies of air pollutants for mechanical ventilated livestock and poultry housing—,” *A review. Atmosphere,* vol. 13, no. 3, p. 452, 2022.

[35] C. W. Ritz, B. D. Fairchild and M. P. Lacy, "Litter quality and broiler performance," *Bulletin,* vol. 1267, pp. 1-7, 2005.

[36] M. M. Sawaf, “Assessment of Gaseous Air Pollution and Litter Moisture Content in Broiler Houses. Faculty of Agricultural Engineering, Department of Animal Production, Tishreen University, Ladakia, Syria.,” *The syrian Journal for Agricultural Researchs,* vol. 12, no. 2, pp. 195-207, 2025.

[37] I. U. Sheikh, S. S. Nissa, B. Zaffer, K. H. Bulbul, A. H. Akand, H. A. Ahmed, D. Hasin, D. Hasin, I. Hussain, S. a. Hussain and S. A. and Hussain, “Ammonia production in the poultry houses and its harmful effects,” *Int. J. Vet. Sci. Anim. Husb,* vol. 4, no. 3, pp. 30-33, 2018.

[38] LPELC, “Litter management strategies in relation to ammonia emissions from floor-raised birds(reprinted),” in *Mitigating Air Emissions From Animal Feeding Operations Conference (reprinted),* 2019.

[39] M. Knížatová, M. J. Š, I. Brouček, J. Karandušovská and J. Mačuhová, “The influence of litter age, litter temperature and ventilation rate on ammonia emissions from a broiler rearing facility,” *Czech Journal of Animal Science,* vol. 55, no. 8, pp. 337-345, 2010.

[40] S. Gençoğlan and C. Gençoğlan, " The effect of the litter materials on broiler chickens welfare and performance," *Turkish Journal of Agriculture-Food Science and Technology,* vol. 5, no. 12, pp. 1660-1667, 2017.

[41] M. Czarick, B. Fairchild, G. Ashabranner and W. Strictland, “DOL 53 ammonia sensor (Poultry Housing Tips, Vol. 32 No. 1),” University of Georgia Department of Poultry Science, 1 January [illegible]. [Online]. Available: https://www.poultryventilation.com/resources/dol-53-ammonia-sensor/. [Accessed 11 Augest 2025].

[42] M. Czarick and M. Lacy, “Controlling Litter Moisture and Ammonia Poultry Housing Tips, Vol. 9 No. 3,” University of Georgia Department of Poultry Science, 1 feberwary 1997. [Online]. Available: https://www.poultryventilation.com/wp-content/uploads/vol9n3.pdf. [Accessed 5 7 2025].

[43] R. C. Lima, E. R. Freitas, H. M. Gomes, C. B. Cruz and D. R. Fernandes, “Performance of broiler chickens reared at two stocking densities and coir litter with different heights,” *Revista Ciência Agronômica,* vol. 49, no. 3, pp. 519-528, 2018.