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Evaluation of a sprinkler cooling system on inhalable dust and ammonia concentrations in broiler chicken production

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Abstract

Workers are exposed to dust in broiler chicken production during daily work activities. Poultry dust may contain inflammatory agents (e.g., endotoxin) and inhalation exposure has been associated with pulmonary symptoms. Current practice to reduce worker exposure to poultry dust is the use of respiratory protection (e.g., elastomeric face-piece respirator with a P100 and ammonia chemical cartridge). Limited research has been conducted to evaluate engineering controls to reduce dust and ammonia concentrations in broiler chicken production; therefore, the purpose of this research was to evaluate the effectiveness of a water sprinkling system to reduce inhalable dust and ammonia concentrations in a broiler chicken house.

Inhalable dust and ammonia concentrations were measured daily for the production cycle of a flock of broiler chickens (63 days). Inhalable dust was measured gravimetrically using an inhalable sampler and ammonia was measured by a direct reading sensor. Sampling was performed on a stationary mannequin inside two broiler chicken houses. One house used a sprinkler cooling system to deliver a water mist throughout the house and the second house was an untreated control. The sprinkler system activated after day 5 of chicken placement, releasing water periodically from 6 am to 10 pm. The amount of sprinkling increased at day 10 and day 15 as recommended by the manufacturer.

Geometric mean (GM) inhalable dust concentrations measured in the treatment house (5.5 mg/m^3) were not different ($p = 0.33$) than those found in the control house (6.0 mg/m3). The GM ammonia concentrations were also not different ($p = 0.34$) across the treatment and control house [10.6 ppm (GSD: 1.80); GM 9.51 ppm (GSD: 1.77)], respectively. The use of cost effective engineering, administrative and personal exposure controls are needed in the poultry industry to effectively reduce worker's exposure to hazardous concentrations of dust and ammonia.

Introduction

Indoor air contaminants such as dust and gases are present in concentrations that may be hazardous to worker health in poultry production. Workers are exposed to inorganic and organic dust as well as ammonia, hydrogen sulfide and microorganisms during daily work activities.[1,2] Organic dust in poultry production is composed of feed, feces, uric acid, feathers, bacteria, and fungi.[2,3] Hazardous concentrations are due to inadequate ventilation and some evidence suggests that indoor air contaminant concentrations increase in the winter months. Also, as birds age, fecal and urine biomass concentrations increase during the growth cycle and feather debris increases with bird size.[4]

Workers in animal production have a higher prevalence of adverse respiratory symptoms than other farmers and rural residents.[1,5,6] Inhalation of dust and/or gases in animal housing can lead to respiratory diseases.[7] Specifically, inhalation exposure to poultry dust has been associated with respiratory symptoms and lung diseases among agriculture workers, including broiler chicken production workers.[8–10] Poultry workers may also have sensitization allergic reactions to mold and/or dust mites which thrive in the poultry litter environment.[1]

Chickens raised specifically for meat production (broilers) are produced in floor-housed facilities that are large, open structures. The poultry production houses are designed to provide optimal conditions for broiler chickens to grow, including mechanical systems to deliver feed and water to the birds and environmental systems that provide ventilation and heat.[11] Production time for broiler chickens, from chick placement to harvest, ranges from 28–63 days.[12] During this growth period, workers are responsible for tracking growth, maintaining environmental conditions in the house, removing deceased birds, and performing equipment maintenance.[13] Upon harvest, the birds are removed and the poultry house litter may be tilled to redistribute and/or de-cake the litter. The poultry litter in the house is a combination of bedding, manure, feathers, wasted feed, etc. and may consist of organic matter such as wood chips, rice hulls, or peanut shells.[11] Air within the poultry house is mechanically exhausted to the outdoors to remove moisture, and minimize thermal stress and contaminant concentrations that may be harmful to the flock.

Kirychuk et al.[9] determined that total dust and ammonia exposures were significantly greater among workers in floor housed poultry buildings, compared to cage-housed egg operations. Furthermore, a range of inhalable dust concentrations have been reported in the scientific literature, all of which are above the recommended occupational exposure limit (OEL) of 2.7 mg/m3 for inhalable dust.[14] Specifically, geometric mean inhalable dust concentrations for floor-housed operations in the U.S. were 24 mg/m3,[15] 8–9 mg/m3 in Europe,[16] and 21 mg/m3 in Iran.[17] In the U.K., respirable and inhalable dust concentrations are also significantly higher in floor-housed broiler operations compared to cage operations.[18] Little task specific exposure data are available; however, Louhelainen et al.[19] concluded that workers involved in catching mature broilers at the end of the production cycle were exposed to inhalable dust concentrations at 37.6 mg/m3. This information suggests that workers performing tasks in floor-housed poultry operations are exposed to inhalable dust that may cause health effects. Therefore, research is needed on engineering controls to reduce inhalation hazards (e.g., inhalable dust) within floor-housed broiler chicken.

The current personal inhalation exposure control for dust and ammonia among agricultural workers is the use of respiratory protection (e.g., elastomeric face-piece respirator with a P100 and ammonia chemical cartridge). The National Institute of Occupational Safety and Health (NIOSH) and the Bureau of Labor Statistics (BLS) conducted a survey among employers in the U.S. regarding the use of respirators. According to this survey, within the agricultural, forestry and fishing sectors approximately 5% of workers in these establishments used respirators. Results from this job-related survey specified that over 1,000 farms reported using respirators; however, over 40% of farms indicated that respirator use was voluntary and not required. Little evidence is available that indicates that air sampling is performed to guide the selection of respiratory protection equipment. Also, the majority of workers and respiratory protection program administrators have no formal training in using and selecting respirators. No information exists concerning respirator use among workers involved in broiler chicken production; furthermore, these workers may not receive adequate training on respirator use. Using the industrial hygiene paradigm, engineering controls are prioritized above other control methods. Therefore, an engineering control method is needed to control concentrations of dust and gases in poultry production.[20]

Few engineering controls have been evaluated to reduce dust concentrations in animal production. Coating surfaces with vegetable oil has been used to control dust in swine, cattle, and poultry production. Nonnenmann et al.[21] demonstrated that oil treatments successfully reduce dust concentrations in swine production.[21] However, there were limitations to these trials. Oil sprinkling resulted in worker safety (e.g., slippery conditions in work areas) and production issues (e.g., mite infestation on poultry).[22] Furthermore, using oil sprinkling did not reduce exposure concentrations below the industry specific limit recommended by Donham et al.[14] Also, ammonia concentrations were not reduced in these oil-sprinkling studies.

Strategies for controlling ammonia concentrations that are used currently in commercial poultry production include mechanical and dilution ventilation, litter and manure chemical amendments, litter management strategies, litter moisture management, selection of bedding material, water sprinkling, dietary manipulation, and immunization.[23,24] To date, no strategy has provided the desired control of ammonia concentrations in poultry production, however new technologies such as water sprinkling may provide control of both ammonia and particulate matter.

Water sprinkler cooling systems have been developed for use in broiler production.[24] These sprinkling systems are used to reduce thermal stress in livestock.[25] Several investigations have also shown that fogging, spraying, or sprinkling oil and/or water mixtures may also reduce hazardous concentrations of aerosolized dust.[26–30] Additionally, these water sprinkling cooling systems use a fraction of the water needed to operate other cooling systems (i.e., evaporative cooling).[31] These sprinkler cooling systems are advertised to effectively create activity that moves the birds to feed and water, reduce heat stress mortality, and reduce dust in houses.[32] However, peer reviewed data from studies that used pure water sprinkling systems are limited to substantiate this claim. Although previous studies have not investigated the use of sprinkling systems to reduce ammonia concentrations, houses with these systems can typically be maintained at warmer temperatures than houses using other modes of cooling. Furthermore, ammonia is highly soluble in water; therefore, the water droplets produced by a sprinkling system may absorb ammonia from the room air. If managed properly, the litter moisture in sprinkler houses remains lower and therefore potentially have lower concentrations of ammonia. Water sprinkling systems may work synergistically to cool the birds and decrease dust and ammonia concentrations, thereby reducing worker inhalation exposure.

Approximately 40 companies in the U.S. are involved in the business of raising, processing and marketing broiler chickens; these companies directly and indirectly employ approximately 500,000 workers including those working at over 30,000 family farms across the country.[11] Global broiler chicken production has exceeded 80 million pounds each year since 2001;33 the U.S. is the largest producer of poultry meat in the world. Also, poultry production is the largest meat producing industry in the U.S., The National Chicken Council estimated that 40 billion pounds of poultry meat was produced in 2015.[11] The broiler chicken industry is based on standard industry guidelines that all growers are contracted to uphold. Therefore, introducing engineering controls to reduce inhalation hazards has the potential to significantly impact worker health if the control method is required as part of the grower's contractual agreement with the poultry company.

The objective of this study was to evaluate the effectiveness of a water sprinkling system to reduce inhalable dust and ammonia concentrations in a broiler chicken house. Within this study, concentrations of inhalable dust and ammonia within a treatment poultry house were compared to concentrations in a control house.

Methods

Experimental conditions

This study was conducted during the winter of 2015 (January to March) in two broiler production houses located at Mississippi State University (Mississippi State, MS). The buildings were approximately 129 m long, 13 m wide and floor-housed approximately 20,000 chickens for the duration of a broiler growth period (63 days). Both buildings had curtain sided walls; each were equipped with mechanical ventilation and infrared heaters to maintain temperature and relative humidity levels (based on the growth stage of the chickens). The buildings were equipped for transitional ventilation, including ten 48-in (1.3 m) fans and tunnel doors for tunnel ventilation and 62 side air inlets along the length of the house for minimum ventilation; the ventilation systems for both buildings were operated alike during the sample period. Cooling pads were located opposite the fans and 20 infrared heaters (40,000 BTU) were located throughout the house. The litter inside each house was treated with an ammonia amendment (liquid alum and sulfuric acid) prior to the trial.

Sprinkling system

The poultry houses were equipped with commercially installed water-based sprinkler cooling systems (The Weeden Sprinkler System®, Weeden Environments Inc., Woodstock, ON). Traditionally, this sprinkling system is used as a cooling device in poultry production. This low maintenance system consists of the manifold which is installed in the front entrance of the barn and the sprinkler drops which are typically 40 cm long and are placed within 3/4 in (1.91 cm) diameter polyvinyl chloride (PVC) water line attached to the ceiling down the length of the barn. Both houses were equipped with this system; however, only one was activated for the duration of this trial (treatment vs. control). The sprinkler system consisted of two rows of twenty sprinkler heads, each were 6 m apart. Sprinkling occurred daily between 6 am and 10 pm, with the length of sprinkler activation based on days after bird placement in the building. Specifically, the activation schedule was as follows: days 1–4 no sprinkler use, days 5–9 five sec/hr, days 10–14 ten sec/hr, days 15-harvest 15 sec/hr; this schedule followed the manufacturer's recommendation for dust control and bird activity promotion. During 20 sec of water sprinkling, each sprinkler emits 237 mL of water over an area of 47 m2, totaling 18 L of water dispersed throughout the entire house for each sprinkler activation. A diagram of the houses, including the locations of the fans and sprinkling heads is shown in Figure 1.

Sampling

Inhalable dust concentrations were measured with a Button Aerosol Sampler (Catalog Number 225–360, SKC Inc., Eighty Four, PA). Polyvinylchloride filters were used (25-mm, 5 μm pore size; Product Number 225–5–25, SKC Inc., Eighty Four, PA) for sampling and were analyzed gravimetrically and blank corrected. Pre/post flow rate calibration was performed using a field rotameter (Dwyer VFA Series Flow Meter, Dwyer Instruments, Michigan City, IN) calibrated to a primary standard (Defender 510, Mesa Labs, Inc., Butler, NJ). All air sampling was performed using a personal sampling pump (Airchek XR5000, SKC Inc., Eighty Four, PA) operating at 4 lpm. Dust samples were collected for 30 min each day in each poultry house for an entire production cycle (approximately 63 days); sampling occurred approximately 3 hr after sprinkler activation begin each day. The sampler was attached to a stationary mannequin near the breathing zone (1.5 m from the floor) (Figure 2). The mannequin was centrally located between the side-walls, 30.5 m upstream from the exhaust fans, throughout the duration of the experiment. Samples collected during this period were stored in a −20°C freezer before being transported to the laboratory for gravimetric analysis. The filters were placed in a desiccator (RH = 20–30%; temperature = 25 ± 2˚C) for at least 24 hr prior to measurement, and were weighed using a 6-place microbalance (Mettler Toledo Microbalance XP26, Mettler-Toledo International Inc., Greifensee, Switzerland) to the nearest μg. Gravimetric dust concentrations were computed from filter weight gain (blank corrected) and total sampling volume. Inhalable dust concentrations were reported in mg/m3. Temperature (˚C) and relative humidity (%) in both houses were monitored by a direct reading instrument (Enviro-Meter, VWR International, Radnor, PA) to compare across treatment and control buildings (Table 1).

Ammonia gas concentrations were measured using a direct reading sensor (ToxiRAE Pro, Rae Systems, San Jose, CA) located in the breathing zone of the mannequin. Samples were collected in each poultry house for 15 min to correlate with the instrument's short term average logging feature; sampling for dust and ammonia occurred at the same time. The ammonia concentrations were reported in ppm; the sensor had a resolution of 1 ppm. The ammonia sensor logged results every 10 sec; the device was calibrated throughout the sampling period using 50 ppm calibration gas (Product: NLBF100550PN, Midwest Safety Counselors, Inc., South St. Paul, MN).

An optical particle counter (OPC) (model 1.108, GRIMM Technologies, Inc., Douglasville, GA) was used to measure the aerosol inside the treatment and control houses. The OPC measured particle number concentration by size from 0.3–25 μm, separating the concentrations into fifteen bin channels. A stainless steel tube (4-mm outer diameter by 3-mm inner diameter) provided by the manufacturer was used as the inlet. Sampling was conducted in the morning and afternoon for 30 min within each house; the instrument operated at 1.2 lpm and was set to report a size distribution every 6 sec. The instrument was calibrated by the manufacturer prior to starting this experiment. Sampling took place prior to water sprinkling activation to ensure similar particle size distributions within each house. The instrument reported particle number concentrations in #/l for each size bin. A summary of the air sampling monitoring equipment, calibration and contaminant measured is described in Table 2.

Data analysis

Inhalable dust and ammonia measurements collected after sprinkler activation began (Day 5) were analyzed (Table 3). The Shapiro-Wilk normality test was conducted to determine the sample's distribution; data were log-transformed if found to be log-normally distributed. If data were neither log-normally distributed nor normally distributed the data were log-transformed if the distribution became more linear when plotted using log-probability scales. Descriptive statistics were conducted and a two-sample t-test was used to determine statistically significant differences in mean dust and ammonia concentrations measured in poultry houses operating with differing conditions (treatment and control). A chi-square analysis was initially conducted to determine whether the sample variances were significantly different. Measurements greater than three standard deviations from the mean were identified as outliers and removed from the analysis. Data collected with the OPC were used to calculate the count median diameter (CMD) and geometric standard deviation (GSD) of particles measured during each sampling period; these results were calculated using the weighted mean method for determining CMD.[34] Data were analyzed using Microsoft Excel, SAS 9.3 (Cary, NC) and Minitab 17 (State College, PA); a p-value < 0.05 was used as the criteria for statistical significance.

Results

Dust

Fifty-five area dust samples were collected in each house (Figure 3). The inhalable dust concentrations in the treatment house (sprinkler activation) were log-normally distributed ($p = 0.10$); however, the inhalable dust concentrations in the control house (no sprinkler activation) were neither normal ($p = 0.0002$) nor log-normally distributed ($p = 0.02$). The geometric mean dust concentration for the treatment house was 5.52 mg/m3 (GSD: 1.59) and the geometric mean dust concentration for the control house was 6.00 mg/m3 (GSD: 1.75).

Statistical analyses were completed on the log-transformed data to determine if there were significant differences in geometric mean inhalable dust concentrations measured in poultry houses operating under the two conditions. The geometric mean inhalable dust concentrations were not different between the treatment and control houses ($p = 0.33$; Figure 4).

The OPC was used to evaluate whether the particle size distributions were similar across the treatment and control houses. Prior to water sprinkling activation, the CMD and GSD of dust particles measured in each house (morning and afternoon) were similar; these results are highlighted in Table 4.

Ammonia

Fifty-five area measurements of ammonia were also collected in each house. The distribution of the ammonia concentrations within the treatment and control houses did not pass a normality test (normal: $p \le 0.05$, log-normal: $p \le 0.05$). Log-normalizing the data did make the distribution more linear when plotted; therefore, the ammonia data were log-transformed. The geometric mean ammonia concentration within the treatment house was 10.6 ppm (GSD: 1.80); the geometric mean concentration within the control house was 9.51 ppm (GSD: 1.77), which were not significantly different ($p = 0.34$; Figure 5).

Discussion

Geometric mean inhalable dust concentrations collected in the treatment house (5.52 mg/m3) were lower than those found in the control house (6.00 mg/m3); however, the difference was not statistically significant. These concentrations were similar to those found in a previous study by Ellen et al.[16] Although the sampling time was much shorter in this study, the concentrations were consistent with those found in broiler production houses in Canada as well; Just et al.[35] measured inhalable dust concentrations ranging from 0.02–81.33 mg/m.[3,35]

Measurements obtained using the OPC verified that particle size distributions were similar within both houses prior to sprinkler activation. Dust concentrations did not increase as the birds aged and become larger in size (Figure 3). Inhalable dust concentrations remained relatively constant during the sampling period, contrary to what previous research has shown. Lawniczek-Walczyk[4] found that contaminant concentrations increase toward the end of the growth period as a result of increased fecal and urine biomass and feather debris as birds grow.

Inhalable dust concentrations were not reduced ($p = 0.33$), therefore, using the water-sprinkler as an engineering control for dust was ineffective in this experiment. The magnitude of inhalable dust and ammonia concentrations were above recommended limits of 2.7 mg/m3 and 12 ppm for inhalable dust (Figure 4) and ammonia (Figure 5), respectively, for the poultry industry.[14] Therefore, using this sprinkling technology did not reduce or eliminate the need for respiratory protection. Adverse health effects have been observed with poultry dust concentrations of this magnitude and respiratory protection should be used to decrease exposures until controls are in place that mitigate the hazards.[14]

Temporal, spatial, and environmental factors were controlled for in this experiment. Sampling was completed in a location 30.5 m upstream from exhaust fans in the tunnel-ventilated houses; this location was stationary throughout the entirety of the experiment and sampling was completed at the same location in each house. Also, due to air movement throughout the house, this location likely has the highest contaminant concentrations and may be representative of the worst case scenario for workers. Contaminant concentrations may have been influenced by seasonal weather. However, to control for weather variability, paired sampling was employed between the treatment and control buildings. Because sampling was conducted simultaneously in each house, error attributed to these factors would be non-differential.

Limitations

Sampling was conducted at one broiler chicken farm; this could impact the generalizability of the results. The sprinkler's activation settings may have also impacted the reduction of inhalable dust and ammonia; however, the manufacturer's recommendations for sprinkling duration and frequency were used in this study. A future experiment could focus on the comparison of inhalable dust and ammonia concentrations collected under a variety of sprinkling conditions (i.e., variety of sprinkling schedules and amount of water delivered during each activation) paired with the introduction of a chemical litter amendment.

Future research should evaluate the effectiveness of using a different sprinkler activation schedule, and increase the frequency of dust and ammonia measurements. More trials with sprinkling systems may prove to reduce ammonia concentrations. If managed correctly, houses with sprinkling systems can be maintained with higher temperatures and a lower relative humidity, compared to houses with evaporative cooling systems. These factors contribute to moisture reduction within the poultry litter; consequently, less expression of ammonia gas is detected within the chicken house. Also, adding liquid chemical amendments to the poultry house litter in addition to the sprinkler system, may reduce re-aerosolization of dust in the poultry house.

Conclusion

Inhalable dust and ammonia concentrations were not significantly reduced in a broiler chicken house by using a water sprinkling system advertised to decrease dust and thermal stress among chickens. Additional research is needed to further understand inhalation exposure hazards and the use of multiple exposure control technologies synergistically. The use of cost effective engineering, administrative and personal exposure controls are needed in the poultry industry to effectively reduce worker's exposure to hazardous concentrations of dust and ammonia. Continuous collaboration between research institutions and industrial partners is essential to develop conclusive research that reduces exposures, controls hazards, and promotes worker health.

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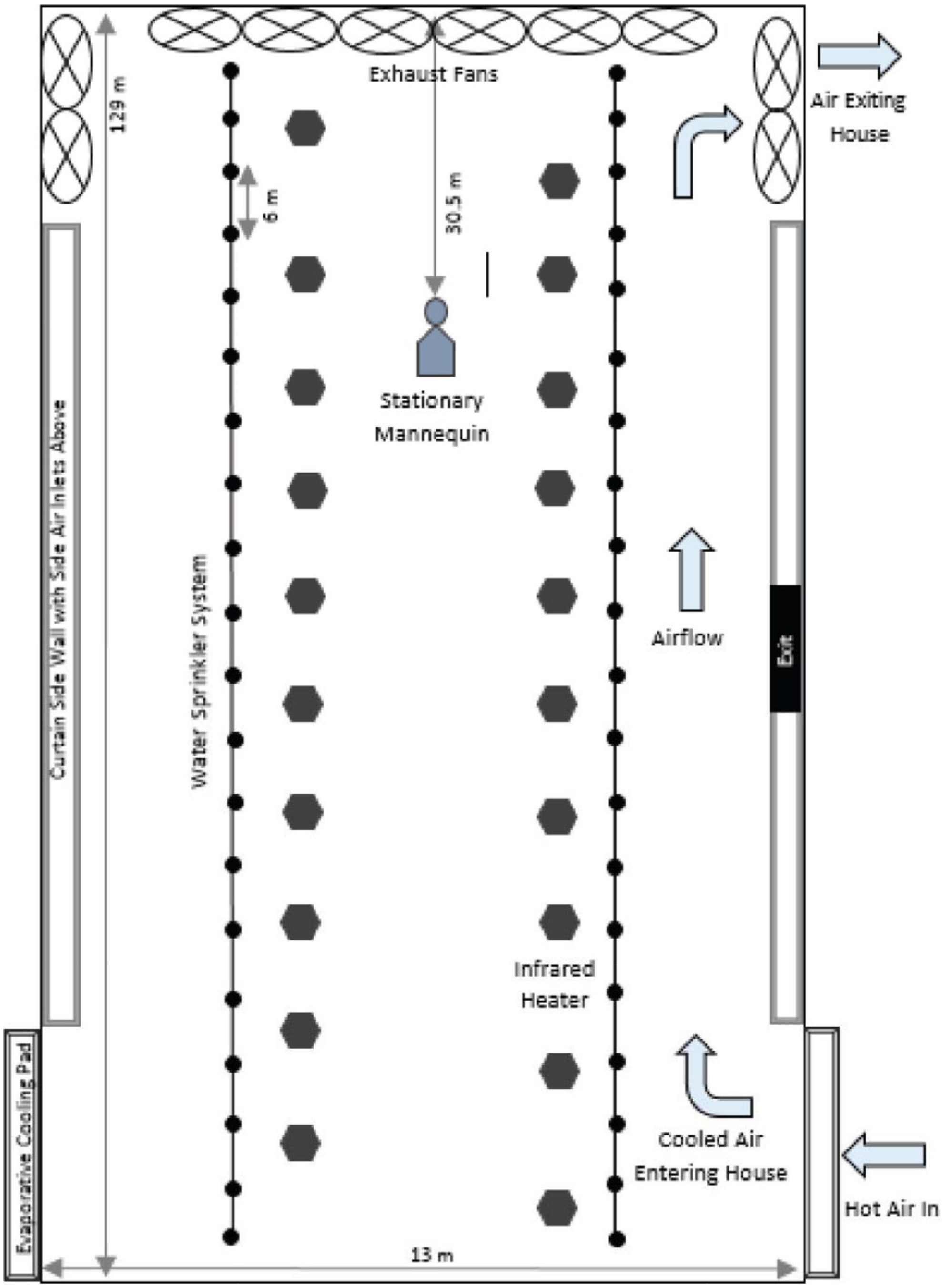

Figure 1.
Aerial view schematic of broiler chicken house.

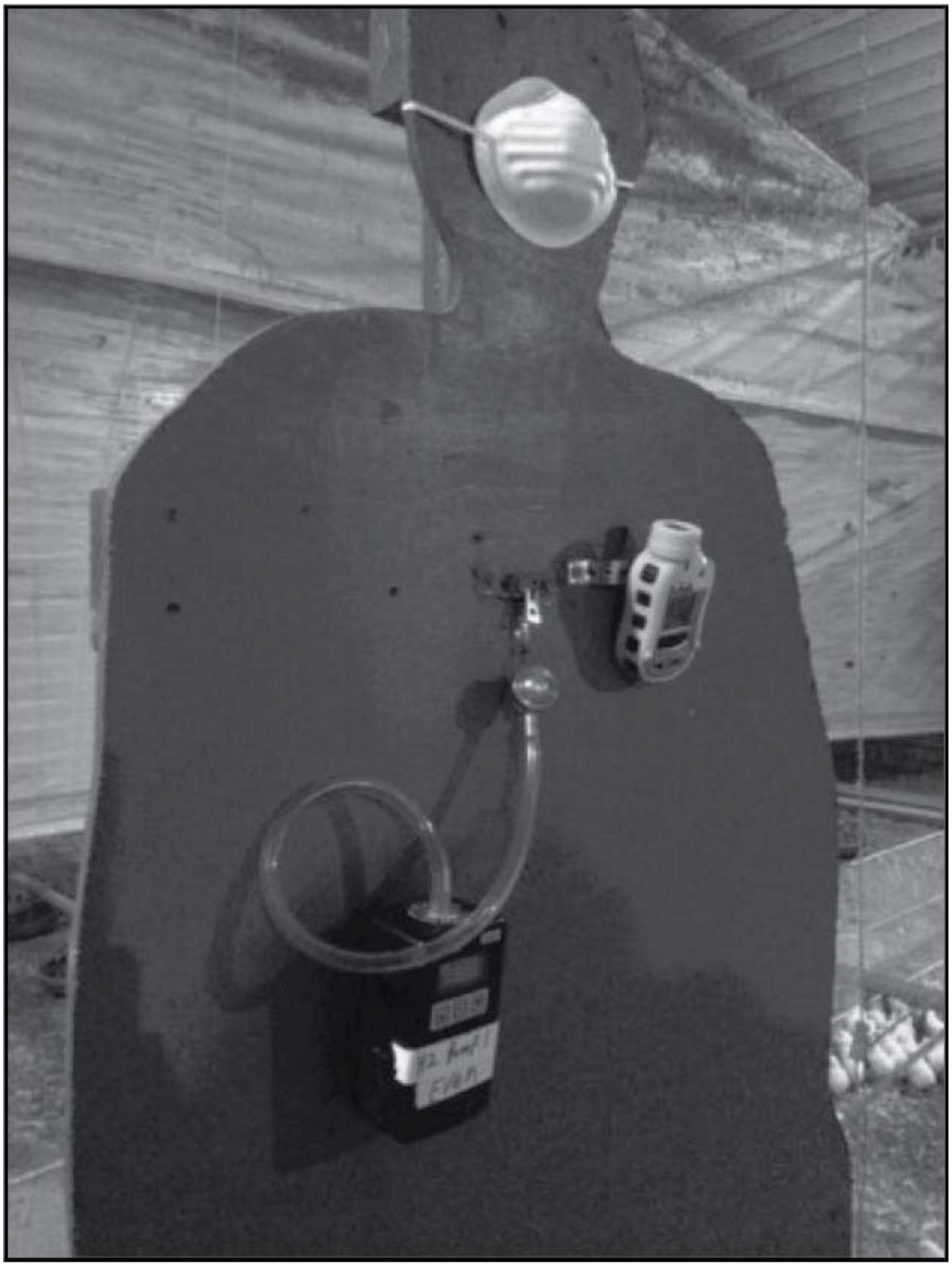

Figure 2.
Sampling equipment on stationary mannequin.

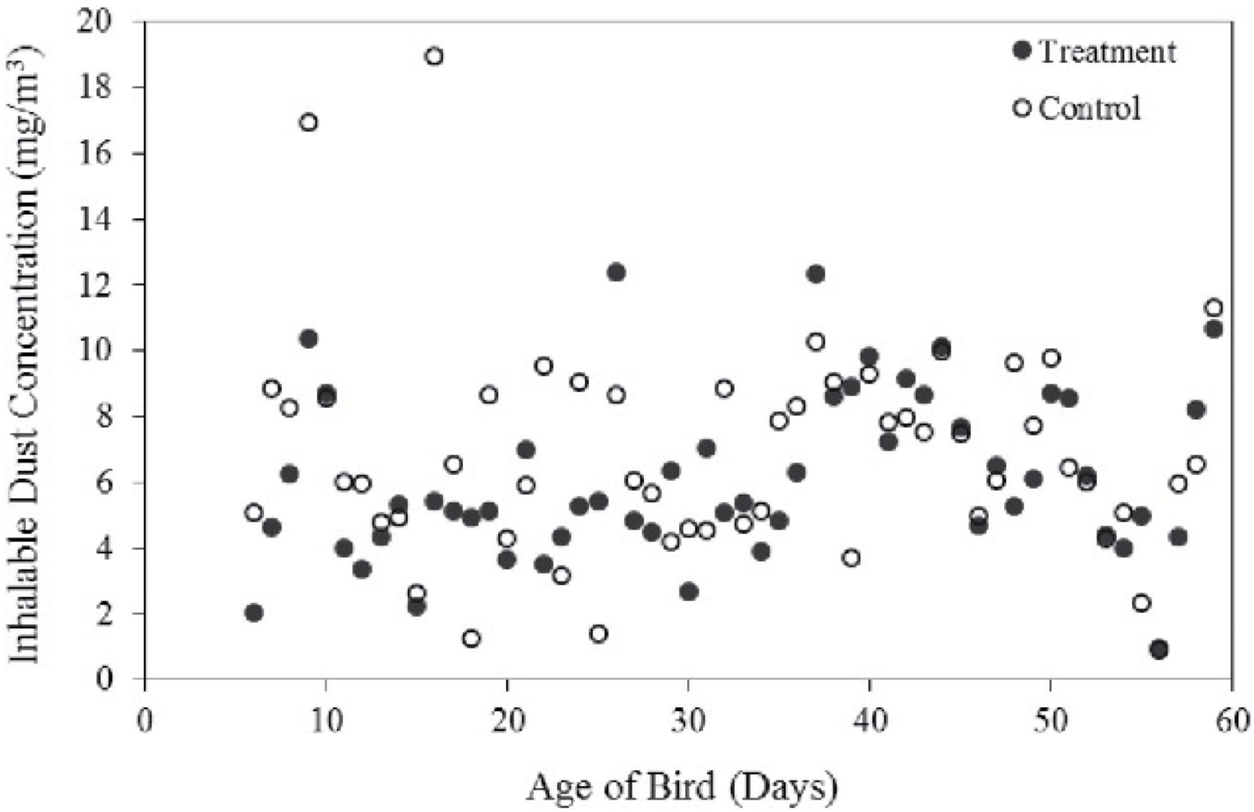

Figure 3.
Inhalable dust concentrations in each broiler chicken house throughout the growth period

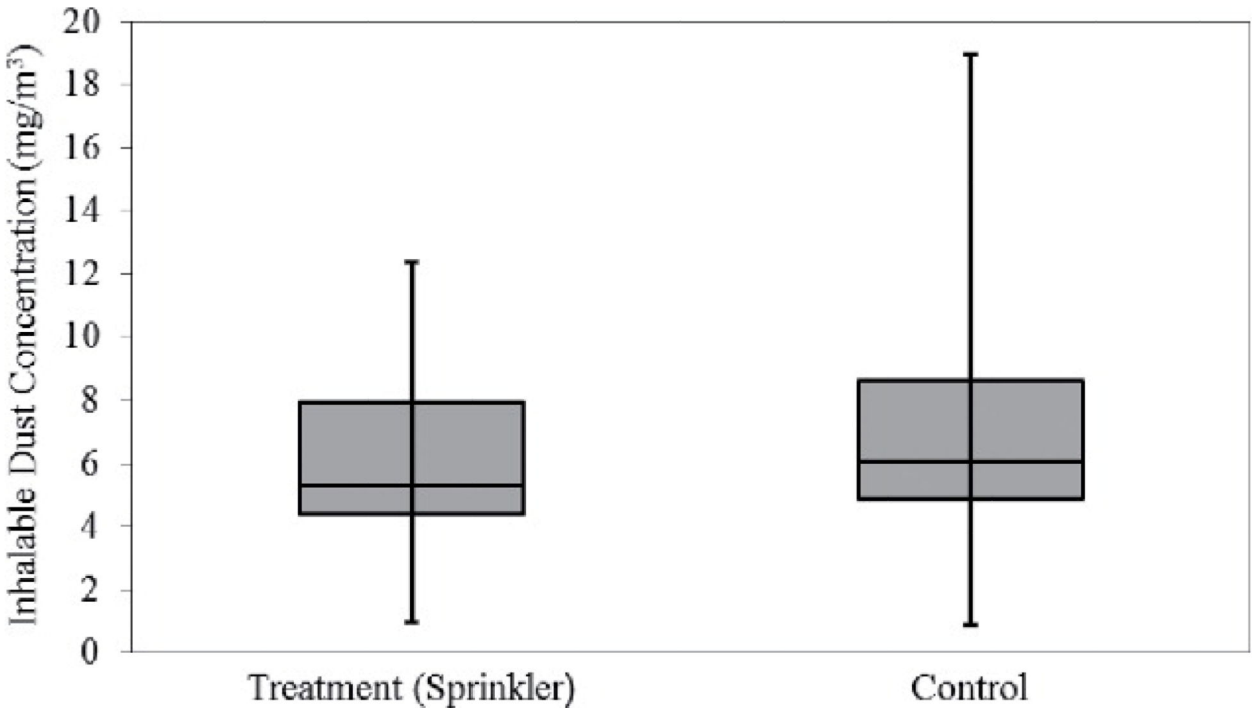

Figure 4.
Comparison of inhalable dust concentrations in broiler chicken houses across the experimental conditions using water based sprinkling system (N = 55 for each condition). The center horizontal line is the median concentration measured in the house; the error bars represent the highest and lowest concentrations measured.

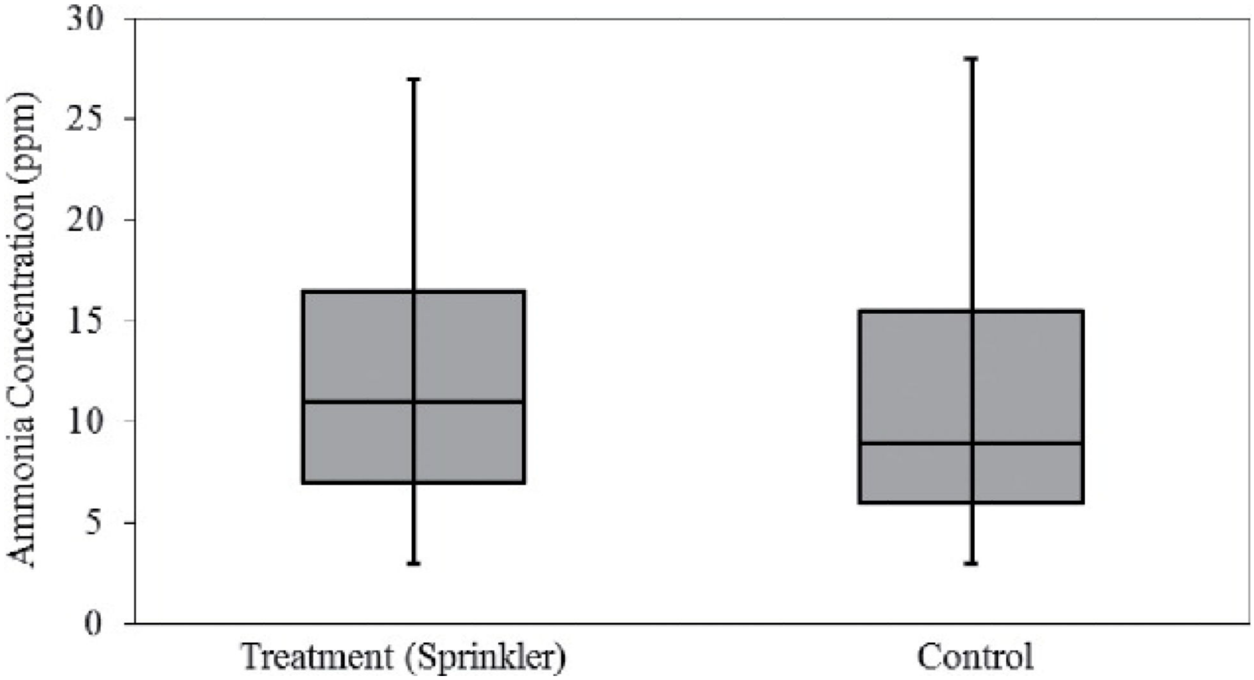

Figure 5.

Comparison of ammonia concentrations in broiler chicken houses across the experimental conditions using water based sprinkling system (N = 55 for each condition). The center horizontal line is the median concentration measured in the house; the error bars represent the highest and lowest concentrations measured.

Table 1.

Environmental conditions evaluated within broiler chicken houses.

Condition, units	Control House Mean (SD)	Treatment House Mean (SD)
Indoor Temperature, °C	19.6 (3.1)	19.2 (2.3)
Indoor Relative Humidity, %	59.5 (10.6)	61.8 (8.8)

Table 2.

Summary of air quality monitoring equipment.

Contaminant, units	Device	Operation	Calibration
Inhalable Dust, mg m^{-3}	Button Aerosol Sampler-PVC filter with 5-μm pore	4 lpm,Airchek XR5000	Rotameter,SKC Multi-Purpose Calibration Chamber
Dust, direct-reading	Portable Aerosol Spectrometer 1.108 (GRIMM Technologies, Inc.)	1.2 lpm, 6-sec logging interval	Performed by Manufacturer
Ammonia, ppm	ToxiRAE Pro (Rae Systems, San Jose, CA)	10-sec logging interval	NH_3 = 50 ppm
Temperature, °CRelative Humidity, %	VWR Enviro-Meter (VWR International, Radnor, PA)	60-sec logging interval	Performed by Manufacturer

Table 3.

Contaminant concentrations measured within broiler chicken houses.

Inhalable Dust (mg/m^3)		Ammonia Gas (ppm)	
Control	**Treatment**	**Control**	**Treatment**
5.43	3.41	22	21
5.09	2.04	23	17
8.87	4.64	21	15
8.25	6.26	19	11
16.97	10.40	19	14
8.54	8.73	10	10
6.02	4.02	8	8
5.95	3.37	7	7
4.79	4.34	7	7
4.92	5.31	7	7
2.64	2.24	6	5
18.95	5.43	6	5
6.56	5.11	5	4
1.28	4.96	4	4
8.64	5.12	5	4
4.30	3.68	5	3
5.91	6.98	5	5
9.56	3.53	5	5
3.17	4.35	5	6
9.08	5.27	4	5
1.38	5.41	5	5
8.68	12.39	7	9
6.07	4.82	6	6
5.68	4.52	6	10
4.21	6.35	6	11
4.58	2.70	6	10
4.54	7.04	6	13
8.84	5.08	7	14
4.74	5.37	6	11
5.12	3.88	6	9
7.88	4.83	9	13
8.30	6.29	11	16
10.28	12.35	11	21
9.04	8.61	11	15
3.72	8.92	15	20
9.28	9.82	12	20

Inhalable Dust (mg/m^3)		Ammonia Gas (ppm)	
Control	**Treatment**	**Control**	**Treatment**
7.85	7.23	14	20
7.98	9.18	16	18
7.53	8.67	19	27
9.97	10.12	19	23
7.48	7.70	20	26
4.98	4.68	13	14
6.06	6.52	25	21
9.64	5.27	15	14
7.74	6.11	18	15
9.81	8.73	22	16
6.44	8.54	16	20
6.01	6.22	13	11
4.28	4.38	8	8
5.07	3.99	13	10
2.35	4.98	6	11
0.90	0.99	3	3
5.96	4.36	11	11
6.57	8.22	12	19
11.31	10.69	28	25

Table 4.

CMD of dust particle distributions measured using an OPC in chicken houses.

Poultry House	Time of Day[a]	CMD (μm)	GSD
Control	Morning	0.755	2.523
	Afternoon	0.740	2.493
Treatment	Morning	0.711	2.442
	Afternoon	0.702	2.422