Endotoxin and Dust at Respirable and Nonrespirable Particle Sizes are not Consistent Between Cage- and Floor-Housed Poultry Operations

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Background: Individuals engaged in work in intensive animal houses experience some of the highest rates of occupationally related respiratory symptoms. Organic dust and in particular endotoxin has been most closely associated with respiratory symptoms and lung function changes in workers. It has previously been shown that for intensive poultry operations, type of poultry housing [cage-housed (CH) versus floor-housed (FH)] can influence the levels of environmental contaminants. The goal of the study was to determine the differences in endotoxin and dust levels at different size fractions between CH and FH poultry operations.

Methods: Fifteen CH and 15 FH poultry operations were sampled for stationary measurements (area) of dust and associated endotoxin. Fractioned samples were collected utilizing Marple cascade impactors. Gravimetric and endotoxin analysis were conducted on each of the filters.

Results: When assessed by individual Marple stage, there was significantly greater airborne endotoxin concentration (endotoxin units per cubic meter) in the size fraction >9.8 μm for the FH operations whereas at the size fraction 1.6–3.5 μm, the CH operations had significantly greater airborne endotoxin concentration than the FH operations. Endotoxin concentration in the dust mass (endotoxin units per milligram) was significantly greater in the CH operations as compared to the FH operations for all size fractions >1.6 μm. As such, endotoxin in the respirable fraction accounted for 24% of the total endotoxin in the CH operations whereas it accounted for only 11% in the FH operations. There was significantly more dust in all size fractions in the FH operations as compared to the CH poultry operations.

Conclusions: There is more endotoxin in the presence of significantly lower dust levels in the respirable particle size fractions in CH poultry operations as compared to the FH poultry operations. This difference in respirable endotoxin may be important in relation to the differential respiratory response experienced by CH and FH poultry operation workers.

Keywords: dust; endotoxin; impactor; poultry; respirable; size fractions

INTRODUCTION

Individuals engaged in work in the poultry production industry have the greatest prevalence of lower airways respiratory symptoms (cough, phlegm, wheeze, and shortness of breath), upper respiratory
tract (eye and nose) symptoms, and chronic bronchi-
titis compared to workers from other agricultural indi-
ustries, including swine, cotton, and animal feed
industries (Simpson et al., 1998). Within the poultry
industry, the type of poultry handled appears to influ-
ence the frequency of symptoms such that cage-
 housed (CH) poultry operation workers report
greater frequency of current and chronic upper respira-
tory symptoms with significantly greater current
and chronic phlegm compared to floor-housed (FH)
workers (Kirychuk et al., 2006).

Endotoxin is a common air contaminant in agri-
cultural operations including poultry operations (Just
et al., 2009). Endotoxin is a structural component in
bacteria. An example of endotoxin is lipopoly saccha-
ride found in the outer membrane of gram-negative
bacteria. As compared to the swine, grain, and animal
feed industries, the poultry industry has been shown to
have the highest endotoxin concentrations (endotoxin
units per cubic meter) (Simpson et al., 1998). Dust and
endotoxin levels may be influenced by such sources as
type of bird housing, manure management system, age
and number of birds, type of feed and litter, rate and
type of ventilation, size of building, amount of worker
time spent in direct contact with birds, and general
housekeeping practices (Just et al., 2009). Total dust
samples from poultry operations have shown trends for
FH operations to have lower total endotoxin con-
centrations (endotoxin units per cubic meter) in the
presence of greater total dust concentration as com-
pared to CH operations (Wathes et al., 1997; Larsson
et al., 1999; Golbabaei and Islami, 2000; Kirychuk
et al., 2006). Furthermore, endotoxin is thought to be
a primary agent in the respiratory reaction experi-
enced by workers in livestock industries (Zejda
et al., 1992; Reynolds et al., 1996; Donham et al.,
2000; Dosman et al., 2006). Among poultry workers,
endotoxin concentration in dust mass (endotoxin units
per milligram) has been shown to be a significant pre-
dictor of chronic phlegm (Kirychuk et al., 2006).

Environmental measures

Two stationary measurements (herein referred to as area) and one personal measurement (results not reported here) were carried out simultaneously in each facility. Area measurements occurred over a 4-h sampling period. Sampling stations were located in the center of the barn ~1.5 m above the floor. The area sampling pack included a Marple cascade sampler and ammonia (NH₃) and carbon dioxide (CO₂) passive colorimetric gas diffusion tubes (NH₃ 2.5–1500 p.p.m.-hours, CO₂ 0.13–30 vol%; Gastec, Kanagawa, Japan). Temperature and relative humidity were measured twice during the 4-h sampling period (VelociCalc, 8347A-M-G; TSI Inc., Shoreview, MN, USA).

Dust samples were collected using Marple cascade impactors (Thermo Electron Corp., Waltham, MA, USA). The Marple sampler contained six stages with particle deposition cut-points of 0.52, 0.93, 1.55, 3.50, 6.0, and 9.8 μm. The Marple sampler was connected to a constant airflow pump (SKC, Universal 224-PCXR4; Eighty Four, PA, USA) and run at 2 l min⁻¹ over the 4-h sampling period. Samplers were calibrated pre- and postsampling utilizing a calibration adapter (Anderson Instruments, Smyrna, GA, USA) and a primary flow meter (DC-
lite, DCL-M; Bios International, Butler, NJ, USA).

Methods

Study sites

Poultry operations were classified according to the manner in which the poultry were housed. Operations in which poultry were housed on the floor were classified as FH and operations in which poultry were housed in cages were classified as CH. Participation was by invitation and sites were chosen from the available population in the province of Saskatchewan. Operations invited to take part were chosen to closely represent the western Canadian poultry industry (flock size, manure management system, and poultry breed). Sites were not chosen if a producer had more than one type of operation (both CH and FH poultry operations). To have the power to address the hypothesis, it was determined that a sample size of 15 operations from each facility type would be required. Of the 78 CH poultry operations in Saskatchewan, 15 (19%) were invited to take part in the study while 15 (20%) of the FH operations (of 73) were invited to take part. One barn on each site was studied during the winters of 2005 and 2006. Sites were located in the province of Saskatchewan. Ethics approval for the project was granted by the University of Saskatchewan.

Study designs

Operations were invited to take part while 37 (48%) of the CH and 15 (20%) of the FH operations were invited to take part. One barn on each site was studied during the winters of 2005 and 2006. Sites were located in the province of Saskatchewan. Ethics approval for the project was granted by the University of Saskatchewan.

Environmental measures

Two stationary measurements (herein referred to as area) and one personal measurement (results not reported here) were carried out simultaneously in each facility. Area measurements occurred over a 4-h sampling period. Sampling stations were located in the center of the barn ~1.5 m above the floor. The area sampling pack included a Marple cascade sampler and ammonia (NH₃) and carbon dioxide (CO₂) passive colorimetric gas diffusion tubes (NH₃ 2.5–1500 p.p.m.-hours, CO₂ 0.13–30 vol%; Gastec, Kanagawa, Japan). Temperature and relative humidity were measured twice during the 4-h sampling period (VelociCalc, 8347A-M-G; TSI Inc., Shoreview, MN, USA).

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Each stage of the Marple sampler housed a pre-weighted radial slit polyvinyl chloride filter (5 μm pore size; Thermo Electron Corp., Waltham, MA, USA). One field blank was processed for each sampling day and was handled in the same manner as the experimental filters except no air was drawn through the filter. To reduce the impact of humidity on gravimetric analysis, filters were desiccated before and after sampling. The cascade impactor with filters was placed in a sealed glass vessel containing desiccant for 12 h prior to initial weighing and postsampling. Filters were gravimetrically analyzed for dust (milligrams of dust (mg) and milligrams of dust per cubic meter of air (mg m\(^{-3}\))) (MX5 microbalance; Mettler-Toledo, Greifensee, Switzerland).

Kinetic-QCL Limulus Amebocyte Lysate (LAL) assay (Escherichia coli O55:B5; Cambrex BioScience Walkersville Inc., Walkersville, MD, USA) was undertaken on each of the filters and field blanks for determination of endotoxin [airborne endotoxin concentration (endotoxin units per cubic meter of air) and endotoxin in the dust mass (endotoxin units per milligram of dust)]. Individual dust filters were extracted in 10 ml of sterile pyrogen-free water (LAL reagent water; BioWittaker, Walkersville, MD, USA) in a 50 ml centrifuge tube and rocked at room temperature for 60 min (Labquake shaker; Labindustries, Berkeley, CA, USA). Undiluted and dilutions at 10, 100, and 1000 were analyzed using kinetic-QCL assay (Cambrex BioScience Walkersville Inc.) and interpreted against a standard curve optimized to be linear from 0.005 to 50.0 EU ml\(^{-1}\). Endotoxin samples were referenced to the reference standard endotoxin: EC-6.

**Questionnaires**

A general poultry operation questionnaire was administered and completed by each poultry operation manager during the sampling period. The information collected included breed, number and age of birds, size and age of barn, and other operation-related information. This same questionnaire had been utilized in previous studies (Kirychuk et al., 2003, 2006).

**Statistical analysis**

Analyses were completed using SPSS version 16 and SAS version 8.2. Categorical variables were described using frequencies and percentages. Arithmetic means and standard error or standard deviations (SD) were used to describe continuous variables. Analyses on environmental variables were completed after log transformation and the geometric mean (GM) and geometric standard deviation (GSD) were used to describe the environmental data, including dust, endotoxin, carbon dioxide, and ammonia. Comparisons of dust and endotoxin data between poultry housing types were completed at (i) the individual stage, (ii) combining all Marple stages (total sample, Stages 3–8), (iii) as well as after stratification into respirable (Stages 5–8, 0.5–6 μm) and nonrespirable fractions (Stages 3 and 4, >6 μm). Spearman’s correlations (nonparametric) between area dust concentration (milligrams per cubic meter), endotoxin concentration in the air (airborne, endotoxin units per cubic meter) and endotoxin concentration in dust mass (endotoxin units per milligram), and number of birds were computed separately for CH and FH operations. The differences in the means of continuous variables between the two poultry operations were tested using univariate analysis of variance with GMs and confidence intervals reported to describe the differences. For testing the mean differences between CH and FH operations, generalized estimation equations for general linear model were used to adjust for the correlation between repeated area environmental measurements taken in the same barn. Mass median aerodynamic diameter (MMAD) and GSD were calculated using a formula previously described (O’Shaughnessy and Raabe, 2003).

The influence of barn and handling characteristics on the association between dust and endotoxin variables [airborne endotoxin concentration (endotoxin units per cubic meter), endotoxin concentration in the dust mass (endotoxin units per milligram) and dust concentration (milligrams per cubic meter)] and bird housing type (CH or FH) was tested through the use of linear regression. Linear regression models were fitted for the outcomes of dust (milligrams per cubic meter), airborne endotoxin concentration (endotoxin units per cubic meter), and endotoxin concentration in the dust mass (endotoxin units per milligram). First, a crude model was fitted that included only an indicator for type of operation (Model 1). Second, an adjusted model was fitted which included type of operation and a potential confounder, including bird age, feed type, or number of birds (Model 2). Finally, variables that were statistically significant were included in a multiple linear regression model along with the indicator for type of poultry housing. Statistical testing of the differences was completed using generalized estimating equations to account for the clustering of the area samples, i.e. two samples per barn.

**RESULTS**

The study population comprised 15 FH poultry operations and 15 CH poultry operations. On the
study day, the age of the birds was significantly different by type of operation with the CH birds being significantly older than the FH birds (mean ± SD: 47.0 ± 15.4 and 3.2 ± 0.3 weeks, respectively, P < 0.001). The poultry barns were of similar age (mean ± SD: 19.7 ± 12.2 years for CH and 15.3 ± 12.3 years for FH, P = 0.33). The FH poultry operations housed significantly greater number of birds as compared to the CH operations (mean ± SD: 23.4 ± 12.8 and 12.7 ± 12.9 thousand birds, respectively, P = 0.03), with similar birds per square meter (mean ± SD: 19.6 birds m⁻² in the CH operations versus 16.5 birds m⁻² in the FH operations, P = 0.45). Ammonia levels were similar between the two types of operations (GM ± GSD: 7.4 ± 2.5 p.p.m. in CH and 7.1 ± 3.4 p.p.m. in FH, P = 0.90) while carbon dioxide levels were significantly higher in the FH poultry operations (GM ± GSD: 4140.9 ± 1.3 versus 3070.4 ± 1.4 p.p.m., P = 0.01).

By individual Marple stage, there was significantly greater airborne endotoxin concentration (endotoxin units per cubic meter) in the size fraction >9.8 μm for the FH operations as compared to the CH operations (Fig. 1) whereas at the size fraction 1.6–3.5 μm, the CH operations had significantly greater airborne endotoxin concentration than the FH operations. Endotoxin concentration in the dust mass (endotoxin units per milligram, Fig. 2) was significantly greater in the CH operations as compared to the FH operations for all size fractions >1.6 μm. Endotoxin in the respirable fraction accounted for 24% of the total endotoxin in the CH operations whereas it accounted for only 11% in the FH operations. The FH operations had significantly greater dust concentration in the size fractions >3.5 μm (Fig. 3).

By combining all stages of the Marple sampler into a total sample (Stages 3–8 combined), there was significantly greater total dust in the FH poultry operations as compared to the CH operations (Table 1). Total airborne endotoxin concentration (endotoxin units per cubic meter) was significantly higher in the FH operations whereas total endotoxin in the dust mass (endotoxin units per milligram) was significantly higher in the CH poultry operations (Table 1).

Dust and endotoxin stages were stratified into nonrespirable (Stages 3 and 4, >6 μm) and respirable (Stages 5–8, 0.5–6 μm) size fractions (Table 1). Both nonrespirable and respirable dusts were significantly higher in the FH poultry operations as compared to the CH operations. There was significantly greater nonrespirable airborne endotoxin concentration (endotoxin units per cubic meter) in the FH operations as compared to the CH operations and no difference in the respirable airborne endotoxin concentration between the two types of operations. Endotoxin in the dust mass (endotoxin units per milligram) for both respirable and nonrespirable classifications was significantly higher in the CH poultry operations as compared to the FH operations. There was a significantly greater MMAD for the FH

Fig. 1. Airborne endotoxin concentration (endotoxin units per cubic meter) levels in CH (squares) and FH (triangles) poultry operations by Marple impactor size fraction (mean ± 95% CI).
poultry operations [16.56 μm, 95% confidence interval (CI) 14.19–18.85] as compared to the CH operations (12.64 μm, 95% CI 10.23–15.08; *P* = 0.02).

Table 2 outlines the descriptive characteristics including barn and handling variables in the CH and FH poultry operations. When comparing endotoxin levels by the types of feed utilized by the poultry operations, there was higher endotoxin when using pellets/crumb feed (GM 2754 EU m$^{-3}$, GM 589 EU mg$^{-1}$) compared to ground meal/mash feed (GM 1349 EU m$^{-3}$, GM 282 EU mg$^{-1}$) in the FH operations.

Number of birds was significantly negatively correlated with endotoxin concentration in the dust mass (*r* = −0.54, *P* = 0.002) and airborne endotoxin concentration (*r* = −0.52, *P* = 0.004) for the CH operations and significantly correlated with airborne endotoxin concentration (*r* = −0.39, *P* = 0.04) for the FH operations. There were significant differences for dust concentration (milligrams per cubic

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**Fig. 2.** Endotoxin in the dust mass (endotoxin units per milligram) levels in CH (squares) and FH (triangles) poultry operations by Marple impactor size fraction (mean ± 95% CI).

**Fig. 3.** Dust concentration (milligrams per cubic meter) levels in CH (squares) and FH (triangles) poultry operations by Marple impactor size fraction (mean ± 95% CI).
but no significant differences between FH and CH in endotoxin after adjusting for feed type, bird age, and number of birds (Table 3).

**DISCUSSION**

After stratifying the Marple cascade samples into respirable and nonrespirable fractions, there was significantly greater endotoxin in the dust mass in both the respirable and the nonrespirable fractions for the CH operations but significantly greater nonrespirable airborne endotoxin concentration in the FH operations. Variations in endotoxin by size fractions have been shown for other agricultural industries (Attwood et al., 1987; von Mutius et al., 2000; Buchan et al., 2002). For poultry operations, in general, greater endotoxin concentration in the inhalable fraction as compared to the respirable fraction for layers and turkeys has been shown in the literature; however, the inhalable and respirable fractions were collected in a small sample size by separate samplers (Schierl et al., 2007). The findings in this study illustrate that when endotoxin was weighted against the mass of dust in the corresponding stage, there was significantly greater endotoxin in the dust mass in the CH operations as compared to the FH operations for all size fractions >1.6 μm and a longer sampling period.

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**Table 1. Dust and endotoxin distribution by total, respirable, and nonrespirable levels in CH and FH poultry operations**

<table>
<thead>
<tr>
<th></th>
<th>CH GM (95% CI)</th>
<th>FH GM (95% CI)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dust concentration, mg m⁻³</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1.69 (1.27–2.23)</td>
<td>4.62 (4.08–5.23)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Nonrespirable</td>
<td>1.32 (1.06–1.63)</td>
<td>3.80 (3.33–4.34)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Respirable</td>
<td>0.48 (0.36–0.64)</td>
<td>0.80 (0.64–1.00)</td>
<td>0.001</td>
</tr>
<tr>
<td><strong>Endotoxin in the dust mass, EU mg⁻¹</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>901.5 (732.9–1108.9)</td>
<td>538.0 (417.8–692.8)</td>
<td>0.006</td>
</tr>
<tr>
<td>Nonrespirable</td>
<td>983.0 (808.0–1195.8)</td>
<td>585.6 (448.0–765.6)</td>
<td>0.005</td>
</tr>
<tr>
<td>Respirable</td>
<td>704.4 (484.6–1023.9)</td>
<td>331.1 (236.6–463.4)</td>
<td>0.005</td>
</tr>
<tr>
<td><strong>Endotoxin concentration in the air, EU m⁻³</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1513.1 (1054.9–2170.2)</td>
<td>2504.1 (1997.2–3139.7)</td>
<td>0.05</td>
</tr>
<tr>
<td>Nonrespirable</td>
<td>1121.6 (763.1–1648.6)</td>
<td>2216.1 (1763.7–2784.4)</td>
<td>0.004</td>
</tr>
<tr>
<td>Respirable</td>
<td>340.4 (236.1–490.6)</td>
<td>272.3 (211.2–351.1)</td>
<td>0.33</td>
</tr>
</tbody>
</table>

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**Table 2. Barn characteristics for CH and FH poultry operations**

<table>
<thead>
<tr>
<th></th>
<th>CH n (%)</th>
<th>FH n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egg collection type</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conveyor belt</td>
<td>15 (100%)</td>
<td>NA</td>
</tr>
<tr>
<td>Cage type</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Double-tier</td>
<td>5 (33.0%)</td>
<td>NA</td>
</tr>
<tr>
<td>Triple-tier</td>
<td>7 (46.6%)</td>
<td></td>
</tr>
<tr>
<td>Four-tier</td>
<td>2 (13.3%)</td>
<td></td>
</tr>
<tr>
<td>Six-tier</td>
<td>1 (6.7%)</td>
<td></td>
</tr>
<tr>
<td>Liter type</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Straw</td>
<td>NA</td>
<td>9 (60.0%)</td>
</tr>
<tr>
<td>Paper</td>
<td>5 (33.3%)</td>
<td></td>
</tr>
<tr>
<td>Sawdust</td>
<td>1 (6.7%)</td>
<td></td>
</tr>
<tr>
<td>Feeding mechanism type</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automatic</td>
<td>15 (100%)</td>
<td>15 (100%)</td>
</tr>
<tr>
<td>Feed type</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ground meal/mash</td>
<td>5 (33.3%)</td>
<td>2 (13.3%)</td>
</tr>
<tr>
<td>Pellets/crumb</td>
<td>10 (66.7%)</td>
<td>13 (86.7%)</td>
</tr>
<tr>
<td>Floor type</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete</td>
<td>14 (93.3%)</td>
<td>10 (66.7%)</td>
</tr>
<tr>
<td>Clay/soil</td>
<td>1 (6.7%)</td>
<td>2 (13.3%)</td>
</tr>
<tr>
<td>Concrete/soil</td>
<td>0 (0.0%)</td>
<td>3 (20.0%)</td>
</tr>
</tbody>
</table>

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**Table 3. Associations between poultry housing type (CH versus FH) and endotoxin and dust measurements using multiple linear regression**

<table>
<thead>
<tr>
<th></th>
<th>β</th>
<th>Standard error</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Endotoxin concentration, EU m⁻³</td>
<td>-0.33</td>
<td>0.28</td>
<td>0.24</td>
</tr>
<tr>
<td>Endotoxin in the dust mass, EU mg⁻¹</td>
<td>0.14</td>
<td>0.23</td>
<td>0.54</td>
</tr>
<tr>
<td>Dust concentration, mg m⁻³</td>
<td>-0.49</td>
<td>0.20</td>
<td>0.02</td>
</tr>
</tbody>
</table>

*β is the regression coefficient for the difference between FH and CH operations after adjusting for bird age, bird number, and feed type, with floor-based housing as the reference category.
time would assist in delineating if there truly are no differences in the smaller size fractions. Endotoxin in the respirable fraction accounted for 24% of the total endotoxin in the CH operations whereas it accounted for only 11% in the FH operations. This 13% difference relates to 61.4 EU; although this difference in endotoxin is relatively small, it is related to the respirable fraction of the samples, which would be the fraction with the greatest influence on the respiratory system. Our previous research utilizing workers from the same cohort as this study showed that workers from CH poultry operations suffered from significantly greater chronic cough and phlegm as compared to workers from FH poultry operations and endotoxin concentration in the dust mass (endotoxin units per milligram) was shown to be a significant predictor of chronic phlegm (Kirychuk et al., 2006). That endotoxin may be a prime agent responsible for the respiratory health effects experienced by poultry workers is supported by the literature (Thelin et al., 1984; Zejda et al., 1992; Reynolds et al., 1996; Larsson et al., 1999; Donham et al., 2000). Research using dose–response data between respiratory outcomes and endotoxin concentration in poultry operations recommended maximum total endotoxin concentration exposure for workers of 100 EU m⁻³ (Donham et al., 2000) and many jurisdictions have been proposing health based limits for endotoxin at levels that are well below the levels of both the respirable and the total endotoxin concentration levels found in this study. Associating endotoxin findings with worker health effects was beyond the scope of this study; however, in light of the endotoxin differences at the respirable level and the known differences in respiratory outcomes of workers from this same cohort (Kirychuk et al., 2006), a larger study that included worker respiratory assessments and environmental measures, including respirable endotoxin levels, would assist in determining if differences in respirable endotoxin at the levels found in this study could be clinically important.

Confounders including feed type, bird age, and number of birds should be considered when reporting differences in dust and endotoxin levels between types of poultry operations. In this study, the sample size was small and may have had an impact on the statistical power at the multivariate level resulting in nonsignificant associations, a larger study would assist in determining the impact of the confounders.

The results showed a negative correlation between number of birds and endotoxin measures. The samples in this study were point estimates taken at different time periods and at different points in the production cycle. It is possible that there are variations over the production cycle for endotoxin as increases in bacteria levels over the fattening period for FH poultry has been shown in the literature (Vucemilo et al., 2007; Oppliger et al., 2008). A study which measures the endotoxin levels over the growth cycle of CH and FH poultry would be a better indicator of the correlations in environmental variables with factors of interest, such as bird number and bird age.

The dust concentration was significantly greater for total, respirable, and nonrespirable classifications in the FH operations as compared to the CH operations. Similar differences in dust concentrations by poultry housing system have been previously shown (Clark et al., 1983; Leonard, 1984; McQuitty et al., 1985; Louhelaïnen et al., 1987; Reynolds et al., 1994; Wathes et al., 1997; Ellen et al., 2000). For both types of operations, the dust MMADs were in the thoracic fraction with an aerodynamic diameter (d₉₀) of >10 µm. At this diameter, particulate would typically deposit within the upper airways (AIHA Aerosol Technology Committee, 1996). Although the MMADs were of a thoracic fraction for both the CH and the FH operations, the inflammatory capabilities of the particulate may differ by housing type. It is possible that bacterial species may differ by operation type due to differences in the sources for the dust and endotoxin, including manure management methods, presence of litter, breed of bird, bird gender, age of bird, presence of feathers, presence of skin, stage of molting, etc. Particle characterization from turkey operations has suggested that fecal material is the main constituent of airborne dust and that the majority of these fecal particles are within the respirable range as defined in this paper (<6 µm) (Feddes et al., 1989). These sources may have an influence on the type and/or levels of bacterial species, the chemical composition of endotoxin present, and perhaps the inflammatory capabilities of the particulate. The literature indicates that bioaerosol levels increase significantly during the fattening period of chickens (Oppliger et al., 2008). Furthermore, it has been suggested that the heterogeneity of the lipid A of endotoxin may be associated with differences in bacterial species and with variations in immunological potency (Helander et al., 1982), respiratory health effects in workers and animals (Helander et al., 1982; Laitinen et al., 2001), and increases in inflammatory markers of exposed agricultural workers (Burch et al., 2010). The LAL assay utilized in this study provides no information on bacterial species or chemical composition of the endotoxin, which may be important in
explaining differences between operations. Given that in this study, there was a greater percentage of endotoxin in the respirable fraction of the endotoxin in the dust mass in the CH operations as compared to FH operations further assessing the dusts for bacterial species and chemical composition may assist in explaining these differences in endotoxin for the two types of poultry operations.

A limitation to these findings is the relatively small sample size. A much larger study would be required to assess if these differences in endotoxin at the respirable level were of clinical significance for the exposed workers. In addition, understanding the types of bacteria and chemical nature of the endotoxin present at the different size stages of particulate for the two types of poultry production would assist in determining if the differences in endotoxin relate to the composition of the bacteria.

CONCLUSIONS

Poultry operations differ in the levels of dust and endotoxin present in the environment depending on the type of poultry housing and confounding variables such as bird age, number of birds, and feed type may be important characteristics in defining these differences. The findings in this study illustrate that when endotoxin was weighted against the mass of dust in the corresponding Marple stage, there was significantly greater endotoxin in the dust mass in the CH operations as compared to the FH operations for all size fractions >1.6 μm. FH poultry operations had significantly greater levels of dust in comparison to operations in which the poultry are housed in cages. In the CH operations, endotoxin in the respirable fraction accounts for a greater percentage of the total endotoxin as compared to the FH operations. Although this difference in endotoxin is relatively small, it is related to the respirable fraction of the samples and may assist in accounting for differential respiratory responses of workers from CH and FH poultry operations.

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REFERENCES


