# Total Dust and Endotoxin in Poultry Operations: Comparison Between Cage and Floor Housing and Respiratory Effects in Workers

S. P. Kirychuk, MSc
J. A. Dosman, MD
S. J. Reynolds, PhD
P. Willson, PhD
A. Senthilselvan, PhD
J. J. R. Feddes, PhD
H. L. Classen, PhD
W. Guenter, PhD

***Objective:*** *The objective of this study was to assess respiratory outcomes and environmental exposure levels of workers in cage-housed and floor-housed poultry operations.* ***Methods:*** *Poultry operations were evaluated for total dust, endotoxin, and ammonia, and respiratory symptoms and lung function tests of workers were conducted.* ***Results:*** *Workers in floor-housed poultry operations had significantly greater exposures to total dust and ammonia, whereas workers from cage-housed poultry operations reported greater frequency of current and chronic symptoms overall and significantly greater current and chronic phlegm (39% vs 18% and 40% vs 11%, respectively). Endotoxin concentration (EU/mg) was a significant predictor ($P = 0.05$) of chronic phlegm for all poultry workers.* ***Conclusions:*** *Greater endotoxin concentration in the presence of significantly lower total dust, in conjunction with greater respiratory symptoms in workers from cage-housed poultry operations, as compared with workers from floor-housed poultry operations, appears to indicate that differences in environmental exposures may impact respiratory outcomes of workers.* (J Occup Environ Med. *2006;48:741–748*)

From the Institute of Agricultural Rural and Environmental Health (Ms Kirychuk, Dr Dosman), the Vaccine and Infectious Disease Organization (Dr Wilson) and the Department of Animal and Poultry Science (Dr Classen), University of Saskatchewan, Saskatoon, Saskatchewan, Canada; the Department of Environmental and Radiological Health Sciences, Colorado State University Fort Collins, Colorado (Dr Reynolds); the Departments of Public Health Sciences (Dr Senthilselvan) and Agricultural, Food and Nutritional Science (Dr Feddes), University of Alberta, Edmonton, Alberta, Canada; and the Department of Animal Science (Dr Guenter), University of Manitoba, Winnipeg, Manitoba, Canada.

Address correspondence to: S. P. Kirychuk, I.ARE.H, 103 Hospital Dr., P.O. Box 120 R.U.H., Saskatoon, Saskatchewan, Canada, S7N 0W8; E-mail: Kirychuk@sask.usask.ca.



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Individuals engaged in poultry production are exposed to varying concentrations of airborne contaminants, including organic dusts, gases, endotoxin, fungi, bacteria, and bacterial constituents. Long-term exposure to this environment may put the worker at risk for developing respiratory dysfunction. Simpson et al[1] studied workers in nine different industries and demonstrated that the highest prevalence of work-related lower respiratory tract symptoms (38%), upper respiratory tract symptoms (45%), and chronic bronchitis (15%) were present among poultry handlers, and personal exposure to dust or endotoxin was predictive of symptoms. European studies indicate that 24% of poultry farmers had work-related symptoms (wheezing, breathlessness, and cough without phlegm)[2] and, compared with swine farmers, had lower baseline lung function.[3] In a study conducted in the United States, 53% of workers who had worked greater than 10 years in turkey operations had cough, 40% had phlegm, and 27% wheezed during the winter season.[4]

Although poultry dust is a combination of feed and fecal particles, feathers, skin, fungal constituents, bacteria, viruses, and litter particles,[5] ammonia;[2,3,10,17] dust, and endotoxin are the most frequently reported environmental contaminants in poultry operations and also the contaminants most frequently associated with respiratory effects experienced by workers. The aerobic bacteria common in poultry confinement operations are *Bacillus*, *Micrococcus, Proteus*, *Pseudomonas*, *Staphylococcus spp*, and *Escherichia coli*, whereas the most common anaerobic bacteria are *Clostridia,* and the highest fungi airborne isolates are either *Aspergillus* or *Penicillium* with changes in the levels of bacteria and fungi occurring with pH increases in the litter.[6] Endotoxins are lipopolysaccharide containing fragments of the cell wall of Gram-negative bacteria and are often reported as levels in relation to the measured dust levels. Endotoxin may be primarily responsible for the respiratory effects experienced by workers in livestock confinement operations.[7–11]

There are different types of poultry operations, including housing birds in cages and housing birds on litter on the floor. In the poultry industry, type of production, ie, floor-housed versus cage-housed birds, may influence the levels of various environmental contaminants. Total, inhalable, and respirable dust measurements vary by the aerodynamic size selective properties of the sampling equipment, and in general, total and inhalable dust levels tend to be higher in poultry operations in which birds are housed on the floor compared with operations in which birds are housed in cages. For floor-housed operations in the United States, geometric mean inhalable dust levels were 24 mg/ $m^3$ [12] and in Iran 21 mg/$m^3$.[13] Total dust measurements in floor facilities in Europe ranged from 8 to 9 mg/$m^3$ inhalable dust.[14] In Finland, floor levels ranged from 2 to 9 mg/$m^3$.[15] In the United States, total dust levels in floor-housed bird operations were 9 mg/$m^3$,[16] and in turkey barns in the United States, levels ranged from 7 to 10 mg/$m^3$.[17] In facilities where birds are housed in cages, total dust levels have typically been considerably lower than those from floor-housed facilities with levels in Europe ranging from 1 to 4 mg/$m^3$.[18,19] In a Swedish study, caged layers had much lower total dust levels compared with birds raised on litter on the floor (2–7 mg/$m^3$ and 12–17 mg/$m^3$, respectively).[20] In the United Kingdom, respirable and inhalable dust concentrations were significantly higher in broiler operations (floor-housed) as compared with cage operations.[21] In a study from Canada that looked at particles less than 5 μm in diameter, the opposite was true; facilities that housed birds in cages had higher levels (40 particles/mL)[22] than did facilities that housed birds on the floor (7 particles/mL and 27 particles/mL).[23,24]

Endotoxin levels have been shown to be similar or higher in operations housing birds in cages as compared with the floor-housed poultry operations. Inhalable endotoxin levels in floor-housed U.S. broiler grower operations have been measured at 20 to 60 ng/$m^3$,[16] and at a geometric mean of 210 ng/$m^3$,[12] and between 1440 and 16,512 EU/$m^3$ respirable endotoxin in turkey production in the United States in winter.[17] Endotoxin levels for cage-housed operations have typically been higher than that of floor-housed operations at 130 to 500 ng/$m^3$,[18] and a U.K. study indicated similar inhalable endotoxin levels but higher respirable endotoxin fractions in cage-housed operations as compared with the floor-housed operations.[21]

For poultry workers in general, exposure to the work environment appears to relate to respiratory effects, and significant dose–response relationships for pulmonary function decrements have been shown.[10] The difference in respiratory responses based on the type of poultry operation and related work exposures are not well understood. This study reports the differences in total dust, airborne endotoxin (EU/$m^3$), endotoxin concentration (EU/mg), and respiratory symptoms between workers from cage-housed and floor-housed poultry production operations in Western Canada.

## Materials and Methods

### Study Population

An initial cross-sectional study describing 303 floor-housed and cage-housed poultry workers studied during the winters of 1997 to 1999, in which the 21 subjects from mixed poultry operations were not included in the analysis, has been previously described.[25] During data collection for this cross-sectional study, workers were asked if they would be willing to have their poultry barn environment measured and have lung function tests conducted over their work shift. From this cross-sectional cohort, 74 poultry workers in the provinces of Saskatchewan and Alberta were studied during the winters of 1998 to 2000 and 46 workers from the provinces of Saskatchewan and Manitoba were studied during the winters of 2002 to 2004 for a total of 120 workers studied from the original cross-sectional cohort (see Table 1). There were nine workers from poultry operations who were not included in the analysis because their operations included mixed methods of poultry housing.

Workers were classified according to the type of poultry housing in which they worked:

Floor-housed: broiler/breeder operations, broiler/roaster operations, turkey operations;
Cage-housed: egg/pullet operations; and
Mixed housing: a combination of floor and cage-housed operations.

The study was approved by the ethics committees of the Universities of Saskatchewan, Manitoba, and Alberta and informed consent was received from participants before data collection.

### Environmental Monitoring

Before beginning work, workers were fit with an environmental sampling backpack, which has been previously described, that measured total dust, ammonia ($NH_3$), carbon dioxide ($CO_2$), temperature, and relative humidity over the work shift.[26] Temperature, relative humidity, and carbon dioxide were monitored as indicators of poultry facility ventilation and are not reported further. Ammonia measurements were recorded every 60 seconds over the range of 0 to 50 ppm ±5% using an electrochemical system (Biosystems Inc., Middletown, CT). Total dust and endotoxin were col-

**TABLE 1**
Study Population From the Original Cohort Study and Those Restudied

| | Alberta | Manitoba | Saskatchewan | Total |
|---|---|---|---|---|
| Original cohort | | | | |
| Floor-housed | 98 | 39 | 44 | 181 |
| Cage-housed | 26 | 34 | 62 | 122 |
| Total | 130 | 81 | 113 | 303 |
| Mixed housing | 6 | 8 | 7 | 21 |
| Restudied | | | | |
| Floor-housed | | | | |
| 1998–2000 | 0 | 15 | 12 | 27 |
| 2000–2004 | 0 | 50 | 3 | 53 |
| Total | 0 | 65 | 15 | 80 |
| Cage-housed | | | | |
| 1998–2000 | 0 | 16 | 2 | 18 |
| 2000–2004 | 0 | 7 | 6 | 13 |
| Total | 0 | 23 | 8 | 31 |
| Mixed housing | | | | |
| 1998–2000 | 0 | 1 | 0 | 1 |
| 2000–2004 | 0 | 4 | 4 | 8 |
| Total | 0 | 5 | 4 | 9 |

lected using a Sensidyne constant airflow pump (GilAir-3, Clearwater, FL) run at 2 L per minute with a preweighed glass fiber filter (1.0 μm binder free, type AE; SKC Inc., Eighty Four, PA) in a closed-faced 37-mm cassette. The cassette with filter was attached at the worker's breathing zone. The filter was gravimetrically analyzed for total dust (milligrams of dust/m$^3$ of air [mg/m$^3$]) and with Chromogenic-end point Limulus Amoebocyte Lysate assay (*Escherichia coli* O55:B5; QCL-1000 Chromogenic endpoint assay kits; Cambrex BioScience, Walkersville Inc., Walkersville, MD) for airborne endotoxin and endotoxin concentration (endotoxin units/m$^3$ of air [EU/m$^3$] and endotoxin units/mg of dust [EU/mg]). QCL has a sensitivity range of 0.1 EU/mL to 1.0 EU/mL. Endotoxin samples are referenced to the RSE: EC-6 for conversion to ng/m$^3$. The concentration of endotoxin in a sample is calculated from the values of solutions containing known amounts of endotoxin standard.

## Questionnaires

A previously administered and piloted general health questionnaire was administered to each worker before the beginning of the work shift. General respiratory health questions, including current and chronic respiratory symptoms, were modified from the American Thoracic Society standardized questionnaire.[27] General questions included an overview of the poultry operation, personal occupational history, work-related respiratory symptoms, principal health conditions, current medication use, and smoking history. Pulmonary function tests and an acute respiratory symptom questionnaire were administered before beginning work and repeated again at the end of the work shift. Pulmonary function measurement variables of forced vital capacity (FVC), forced expired volume in 1 second ($FEV_1$), and forced expiratory flow at 25% to 75% of vital capacity ($FEF_{25–75}$) were measured by volume displacement using a Sensormedics dry rolling seal spirometer (Model 922; Sensormedics, Yorba Linda, California). Measurements were made according to the American Thoracic Society. Across-shift differences were calculated by subtracting the post shift measurement from the preshift measurement and dividing by the preshift measurement.

## Statistical Analysis

Analyses were completed using SPSS version 13. Arithmetic means and standard error or standard deviation were used to describe continuous variables, including age, years worked in the poultry barn, time spent in the barn, height, weight, total dust, endotoxin, carbon dioxide, and ammonia. Categorical variables, including respiratory symptoms, gender, and smoking status, were described using frequencies and percentages. Data in tables and figures are displayed in the original scale of measurement. However, because the environmental variables (total dust, airborne endotoxin [EU/m$^3$], endotoxin concentration [EU/mg], and ammonia) were not normally distributed, logarithmic transformations ($\log^e$) were applied to the environmental variables, which normalized the data, before analyses. The differences in the means of continuous variables between the study groups were tested using one-way analyses of variance and *t*-tests. Multivariate logistic regression analyses were used to examine the association between current and chronic respiratory symptoms and environmental variables after adjusting for age, gender, smoking status, number of years worked in the poultry barn, poultry housing method, and worker time spent in the barn. As a result of colinearity, individual logistic regression models were fit for each of the environmental variables.

# Results

Floor-housed operations comprised 67% ($n = 80$), cage-housed operations were 26% ($n = 31$), and mixed operations were 7% ($n = 9$) of the study population. Mixed operations were not included in the analysis of effects due to differences in work environments and exposures.

Figure 1 outlines the environmental results for the cage- and floor-housed poultry operations. After log transforming the data, personal total dust exposures in floor-housed operations were significantly ($p = 0.01$) greater than were the personal total dust exposures in the cage-housed poultry operations. Similarly, ammonia levels in the floor-housed opera-

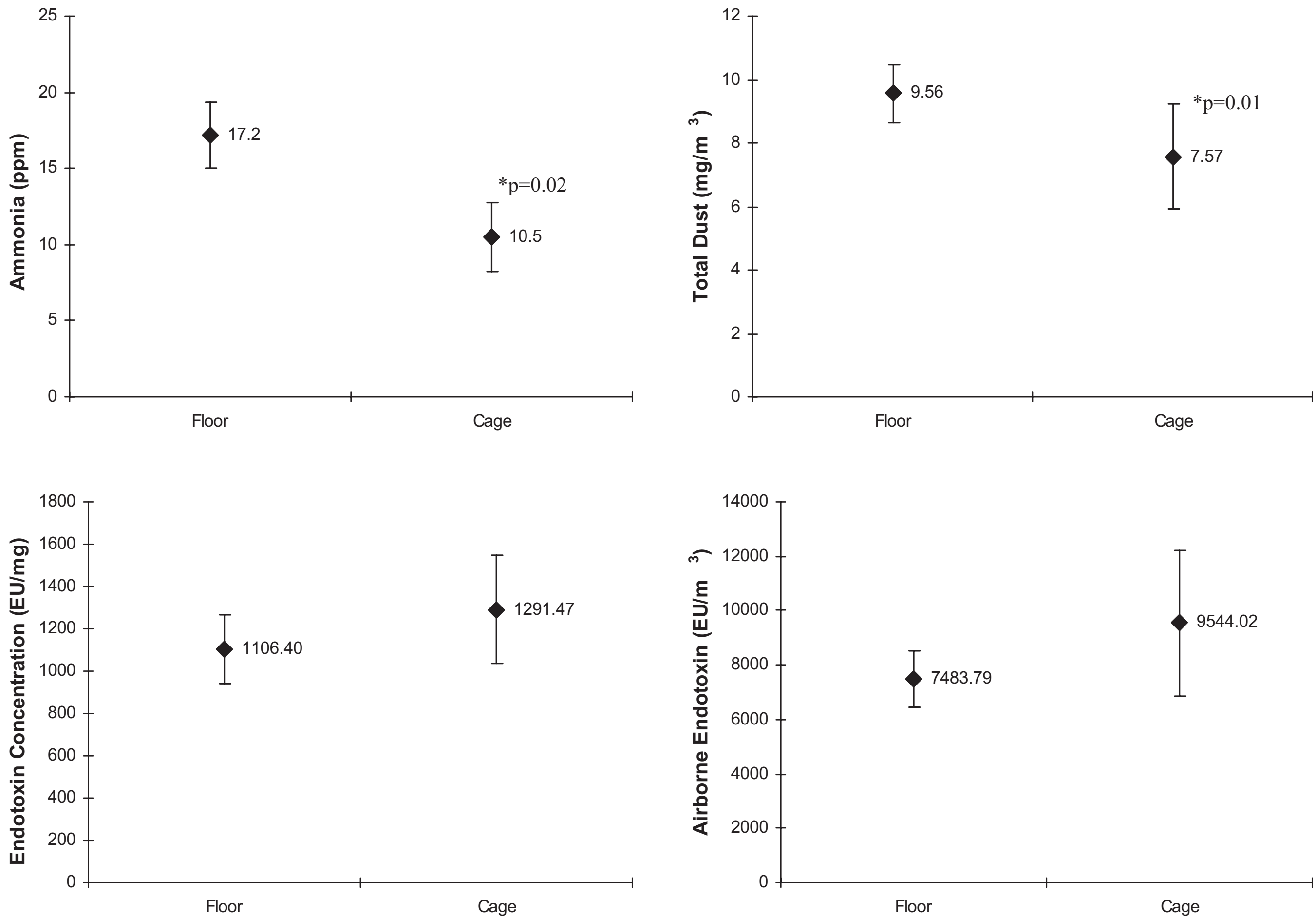


**Fig. 1.** Ammonia (ppm), total dust (mg/m$^3$), endotoxin concentration (EU/mg), and airborne endotoxin (EU/m$^3$) for floor- and cage-housed poultry operations (mean ± standard error).

tions were significantly greater than in the cage-housed poultry operations ($p$ = 0.02). Personal airborne endotoxin (EU/m$^3$) and endotoxin concentration per milligram of dust (EU/mg) exposures were not significantly different between the cage-housed and floor-housed poultry operations, although there was a trend toward higher levels of endotoxin concentration (EU/mg) in cage-housed poultry operations. Furthermore, when looking at the high and low endotoxin concentration (EU/mg) by caged- and floor-housed poultry operations 56% of workers from the cage-housed operations were categorized in the high endotoxin concentration (>6.38 ln [EU/mg]) compared with only 48% of workers from the floor-housed operations, although this difference in proportions was not statistically significant.

As indicated in Table 2, workers from cage-housed poultry facilities were, on average, significantly shorter ($p$ = 0.02) and spent more time in the poultry barns ($p$ = 0.001) as compared with the floor-housed poultry barn workers. There were no differences in age, smoking status, or across-shift values for lung function tests between workers from cage- and floor-housed poultry operations.

There were significant differences in current phlegm ($p$ = 0.02) and chronic phlegm ($p$ = 0.001) between workers from floor- and cage-housed poultry operations (Table 3). Both current and chronic phlegm were reported more frequently in workers from cage-housed poultry operations compared with workers from floor-housed poultry operations (current: 39% vs 18%; chronic: 40% vs 11%, respectively). Although there were some large differences in the prevalence of other respiratory symptoms between groups, with workers from cage-housed operations typically experiencing greater symptoms, there were no statistically significant differences between the two groups for current cough, wheeze, shortness of breath, or chronic wheeze or cough. Overall, the most common symptom reported by poultry workers was current cough (25%), followed by current phlegm (24%) and shortness of breath when hurrying on the level (17%). The most common symptom occurring chronically for all poultry workers was phlegm (19%) followed by wheeze (16%) and cough (13%).

As shown in Table 4, endotoxin concentration (EU/mg) was a significant predictor of chronic phlegm (odds ratio [OR] = 1.69, 95% confidence interval [CI] = 1.01–2.83, $p$ =

**TABLE 2**
Demographics, Pulmonary Function, and Environmental Measurements of Workers From Floor- and Cage-Housed Poultry Operations

| | Floor-Housed | Cage-Housed |
|---|---|---|
| Number | 80 | 31 |
| Age (yr) (mean ± SD) | 42.61 ± 11.50 | 45.74 ± 12.92 |
| Height (cm) (mean ± SD) | 177.18 ± 7.18 | 173.41 ± 8.94* |
| Weight (kg) (mean ± SD) | 85.08 ± 14.72 | 81.96 ± 16.87 |
| Time worked in barn on sampling day (min) (mean ± SD) | 95.38 ± 51.83 | 160.97 ± 146.09† |
| Gender (n) (%) | | |
| Male | 75 (93.7) | 29 (93.5) |
| Female | 5 (6.3) | 2 (6.5) |
| Smoking status (n) (%) | | |
| Nonsmoker | 54 (67.5) | 20 (64.5) |
| Exsmoker | 21 (26.2) | 5 (16.1) |
| Current smoker | 5 (6.3) | 6 (19.4) |
| Across-shift pulmonary function (%) (mean ± SD) | | |
| Forced expired volume in 1 s | 0.17 ± 5.11 | 0.23 ± 5.45 |
| Forced vital capacity | 0.81 ± 4.24 | 1.80 ± 4.43 |
| Forced expired flow at 25%–75% | −1.70 ± 15.96 | −0.86 ± 12.80 |
| Environmental measurements (mean ± SD) | | |
| Total dust (mg/m$^3$) | 9.56 ± 7.95 | 7.57 ± 8.99‡ |
| Endotoxin concentration (EU/mg) | 7483.79 ± 9020.41 | 9544.02 ± 14189.62 |
| Airborne endotoxin (EU/m$^3$) | 1106.40 ± 1420.30 (110.64 ± 142.03 ng/m$^3$) | 1291.47 ± 1349.74 (129.15 ± 134.97 ng/m$^3$) |
| Ammonia (ppm) | 17.2 ± 18.2 | 10.5 ± 11.2* |

Statistical difference: *$p$ = 0.02, †$p$ = 0.001, ‡$p$ = 0.01.
SD indicates standard deviation.

**TABLE 3**
Current and Chronic Respiratory Symptoms of Poultry Workers

| | Floor-Housed | Cage-Housed | Overall |
|---|---|---|---|
| Current symptoms, n (%) | | | |
| Cough | 17 (21.5) | 11 (35.5) | 28 (25.5) |
| Phlegm | 14 (17.7) | 12 (38.7)* | 26 (23.6) |
| Wheeze | 3 (3.8) | 3 (9.7) | 6 (5.1) |
| Shortness of breath | 11 (13.9) | 8 (25.8) | 19 (17.3) |
| Chronic symptoms, n (%) | | | |
| Cough | 8 (10.1) | 6 (19.4) | 14 (12.7) |
| Phlegm | 9 (11.4) | 12 (40.0)† | 21 (19.3) |
| Wheeze | 12 (15.6) | 5 (16.1) | 17 (15.7) |

Statistical difference between cage and floor housed: *$p$ = 0.02, †$p$ = 0.001.

0.05) after controlling for gender, age, years in the poultry industry, time spent in the barn, type of poultry production (cage-housed or floor-housed), and smoking status.

After categorizing the log-transformed endotoxin concentration (EU/mg) into low (<6.36 ln [EU/mg]) and high (>6.38 ln [EU/mg]) levels using the 50th percentile, it was found that high endotoxin concentration was a significant predictor of chronic phlegm for all workers (OR = 5.49, 95% CI = 1.23–24.63, $p$ = 0.03).

## Discussion

Although poultry workers are exposed to a mixture of contaminants in the work environment, endotoxin is thought to be a primary agent responsible for inflammatory reactions experienced by livestock workers.[7] Compared with control subjects and workers from layer operations (in which birds are housed in cages), broiler growers (who work with birds grown on the floor) have shown a greater across-shift decline in forced expired volume in 1 second.[28] Higher dust and airborne endotoxin have been correlated with changes in lung function,[29] and significant dose–response relationships for pulmonary function decrements in poultry workers have been suggested at 2.4 mg/m$^3$ total dust, 0.16 mg/m$^3$ respirable dust, 614 EU/m$^3$ endotoxin, and 12 ppm ammonia.[10] A study looking at airway hyperresponsiveness in naïve subjects exposed to cage- and floor-housed poultry systems found that inhalable endotoxin concentration was similar (100 ng/m$^3$) between the two types of operations but there was twice as much inhalable dust in the floor-housed systems, yet bronchial responsiveness was slightly higher in the persons exposed to the cage-housed environment.[30]

This study reconfirms results from previous studies that poultry workers experience high rates of respiratory symptoms. The results from this study are generally lower than those reported by other studies[1,2,4] but similar to Swedish results.[29]

Particle size, particularly particles of the ultrafine range, appears to be important in respiratory and inflammatory health effects and may be a factor in the results presented here. Ultrafine particles (ie, particles with diameter ≤0.1 μm) can represent a substantial component of particle numbers in total dust and in particulate matter with a diameter of <10 μm ($PM_{10}$), although they would represent only a small fraction of the total mass.[31] Ultrafine particles have a much larger surface area than larger particles, and if ultrafine particles are more toxic than larger particles, adverse effects would be expected at lower mass concentrations because the ultrafine particles would contribute very little to the overall particle mass.[32–36] At low ambient particle mass, concentrations of ultrafine particles can be relatively persistent, whereas at higher concentrations,

**TABLE 4**
Multivariate Logistic Regression Model of Risk Factors for Chronic Phlegm Production in Poultry Workers

| | Odds Ratio (95% Confidence Interval) | *P* Value |
|---|---|---|
| Age | 1.00 (0.94,1.06) | 0.96 |
| Years worked in the poultry barn | 1.00 (0.93–1.05) | 0.76 |
| Time spent in barn on sampling day | 1.00 (1.00–1.01) | 0.19 |
| Type of poultry production | | |
| Floor-housed | 1.00 | |
| Cage-housed | 0.28 (0.07–1.09) | 0.07 |
| Smoking status | | |
| Nonsmoker | 1.00 | |
| Exsmoker | 2.05 (0.31–13.58) | 0.45 |
| Current smoker | 0.08 (0.01–0.55) | 0.01 |
| Endotoxin concentration, ln (Eu/mg) | 1.69 (1.01–2.83) | 0.05 |

Results were adjusted for gender (not significant).

aggregation to larger particle sizes occurs much more rapidly.[33] Factors that suggest that ultrafine particles may be more toxic than larger particles are related to 1) the dosimetric aspects of deposition and disposition of particles; 2) the larger surface area per mass of ultrafine particles may act as a catalyst for reactions; and 3) the increased surface area could act as a carrier for copollutants.[33] One study of poultry confinement operations indicated that respirable suspended particles constituted 4% to 6% of the total suspended particles but the respirable fraction of endotoxin constituted more (11–30%) of the total airborne endotoxin.[16] The average endotoxin concentrations in total dust were between 6 to 16 ng/mg with endotoxin concentration of the respirable fraction considerably higher, ranging from 20 to 40 ng/mg, with the majority of the respirable fraction being $<$3.5 μm in size.[16] This suggests that endotoxin is considerably enriched in the smaller particles. The role of ultrafine particles is yet to be delineated in the poultry work environment, as are the differences in the ultrafine particle concentrations between the two types of poultry operations, and the potential impact on worker health. Ultrafine particles have been associated with increased morbidity and mortality in relation to urban air pollution,[37–42] and it is possible that in the poultry work environment, ultrafine particles and attached copollutants such as ammonia and endotoxin could act alone or synergistically to potentiate respiratory effects in workers.

There is evidence from the swine industry that decreasing airborne dust and endotoxin levels results in significant decreases in total and inhalable dust levels but concomitant increases in the proportion of the diminutive dust (0.3–0.5 μm) with consequential increases in the endotoxin concentration (EU/mg).[8] Among the poultry workers studied here, the personal total dust levels were significantly lower among the workers exposed to the cage-housed poultry as compared with those exposed to the floor-housed poultry, yet there was a trend toward greater endotoxin concentration (EU/mg) for the cage-housed poultry operations. It is possible that the lower total dust in the cage-housed poultry operations could be related to a greater proportion of diminutive or ultrafine particulates present in the work atmosphere, and that these smaller particles, with a lower mass but larger surface area, could carry a greater portion of endotoxin. These smaller particles with higher levels of endotoxin, with potential to penetrate deeper into the lung, might contribute to the greater respiratory effects experienced by the exposed workers in the cage-housed poultry operations.

In a study on floor-housed poultry aged 2 to 6 weeks housed in clean rooms, the greatest number of respirable particles were in the size range 1 to 2 μm followed by 2 to 3 μm.[43] A study of respirable aerosol concentrations in broiler houses (floor-housed) indicated that particles in the size range 1 to 2 μm were consistently greater than particles of the 0.7 to 1 μm size range over a 24-hour period.[44] A study in Canadian broiler barns indicated that for particles greater than 5 μm, there was a 10-fold increase in mean particle concentration over a 7-week growth cycle versus a 1000-fold increase for the size fractions less than 5 μm.[23] Studies from laying houses indicate similar trends, if not to a greater proportion, for particles of a smaller size range. In a U.S. study of particle size distribution in laying houses, only 2.4% of particles were larger than 5 μm and particles of 0.3 to 0.5 μm in diameter accounted for 43.6% of the total number of particles.[16] There is no indication on the level of ultrafine particles in these studies, but the results support the propensity for smaller-sized particles.

There are several limitations to this study, the first of which is sample size. A larger sample size, particularly for the cage-housed poultry operations, would assist in further delineating the results. Second, environmental data collection included only total dust and not inhalable or fractionated dust levels, and these would assist in furthering the hypotheses presented. Differences in operations and work practices between the two types of operations, including worker time spent in direct contact with birds, predominance of female poultry in cage-housed poultry operations, age of the birds, length of time birds have been in housing, and the housing management practices, could result in different dust fractionations and different exposure profiles of endotoxin or other substances that we have not studied here, including other bioaerosols, mold, and fungi, all of which could contribute to the respiratory effects experienced by workers.

The study presented here has found significantly higher total dust and ammonia in facilities in which poultry are housed on the floor as compared with facilities that house poultry in cages, along with trends for higher endotoxin concentration (EU/mg) in the cage housing poultry facilities as compared with the floor housing facilities. In addition, workers from the cage housing facilities reported significantly greater frequency of current and chronic phlegm and greater current cough, wheeze, and shortness of breath; and greater chronic cough and wheeze as compared with workers from the floor-housed poultry facilities. Furthermore, high endotoxin concentration (EU/mg) was a significant predictor of chronic phlegm in poultry workers.

## Conclusions

Despite higher total dust and ammonia exposures in the floor-housed poultry operations, the workers from the cage-housed poultry operations indicated the greater respiratory symptoms. This may be a function of exposure to endotoxin concentration (EU/mg), which was a significant predictor of chronic phlegm, because there was a trend for greater endotoxin concentrations in the cage-housed poultry operations as compared with the floor-housed poultry operations. This study is only able to present the total dust levels, but it is possible that the measured dust from the cage-housed operations represents smaller particle sizes with a larger surface area, and therefore resultant lower total dust concentration, as compared with the floor-housed poultry operation environment. Furthermore, these smaller particles in the cage-housed poultry operations may be enhanced with endotoxin as indicated by the trend to greater endotoxin concentration (EU/mg), and these factors may be important influences on the presence of symptoms in cage-housed poultry workers.

Dust size fractionation, including ultrafine particle sizing and associated endotoxin concentration, in the cage- and floor-housed poultry operations and related respiratory health effects and immune system indicators in workers would assist in further elucidating the relationships between exposures and respiratory outcomes in workers in the industry.

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