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Occupational Exposure to Particulate Matter and Respiratory Symptoms in Portuguese Swine Barn Workers

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OCCUPATIONAL EXPOSURE TO PARTICULATE MATTER AND RESPIRATORY SYMPTOMS IN PORTUGUESE SWINE BARN WORKERS

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Certain environmental conditions in animal and plant production have been associated with increased frequency in respiratory illnesses, including asthma, chronic bronchitis, and hypersensitivity pneumonitis, in farmers occupationally exposed in swine production. The aim of this study was to characterize particulate matter (PM) contamination in seven Portuguese swine farms and determine the existence of clinical symptoms associated with asthma and other allergy diseases, utilizing the European Community Respiratory Health Survey questionnaire. Environmental assessments were performed with portable direct-reading equipment, and PM contamination including five different sizes ($PM_{0.5}$, $PM_{1.0}$, $PM_{2.5}$, $PM_{5.0}$, PM_{10}) was determined. The distribution of particle size showed the same trend in all swine farms, with high concentrations of particles with PM_5 and PM_{10}. Results from the questionnaire indicated a trend such that subjects with diagnosis of asthma were exposed to higher concentrations of PM with larger size ($PM_{2.5}$, PM_5, and PM_{10}) while subjects with sneezing, runny nose, or stuffy nose without a cold or flu were exposed to higher concentrations of PM with smaller size ($PM_{0.5}$ and PM_1). Data indicate that inhalation of PM in swine farm workers is associated with increased frequency of respiratory illnesses.

In the last few years, farmers in Europe and North America have enlarged livestock production techniques by using more enclosed and densely stocked housing. The design of these buildings leads to high animal concentrations, as well as an increase in wastes and feed. The outcomes from these are normally high levels of dusts, gases, microbes, microbial metabolites, and other potential health hazards present in indoor air (Donham et al., 1989; Cole et al., 2000; Cleave et al., 2010; Harting et al., 2012). The mixture and concentrations of these contaminants inside swine buildings varied depending upon numerous factors, including (1) management practices, (2) ventilation and other engineering controls, (3) the age, number, and type of animals in the building, and (4) design and management of the feeding and waste handling systems (Donham, 2010).

Dust particles in this occupational setting contain approximately 25% protein, and range in size from <2 μm to 50 μm in size (Donham and Popendorf, 1985). Normally, one-third of the particles are within the inhalable size range (i.e., <10 μm in size) (Donham and Popendorf, 1985). Fecal material particles are quite small (i.e., ≤10 μm) relative to other dust components, consist of increased concentrations of gut-flora bacteria and exfoliated gut epithelium,

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and are the major concern regarding adverse health effects since these particles reach small airways and alveoli. The larger particles are mainly of feed grain origin and primarily affect the upper airways (Donham, 2000; Donham, 2010).

In addition to particles, indoor environments also contain animal dander, broken bits of hair, bacteria, endotoxins, pollen grains, insect parts, and fungal spores (Donham et al., 1985; Donham, 1986).

The size of dust particles is important and exerts an influence on health effects. Dust particles with a size between 0.5 and 10 μm are generally classified as respirable aerosol particles, which penetrate into lower respiratory system of humans and are attributed to producing respiratory diseases, such as bronchitis, asthma, and pneumonia (Cormier et al., 1990; Olson and Bark, 1996; May et al., 2012). Donham and colleagues (1989) found that exposure to organic dust in concentrations greater than 2.5 mg/m^3 in a pig confinement building was associated with symptoms of respiratory disease. Taking all these facts into consideration, and if swine farm workers do not use respirator protection devices, it is conceivable that if hazardous substances adsorbed to dust particles are inhaled and deposited in respiratory system, this may subsequently result in a potential cause of serious respiratory diseases including asthma, bronchitis, and pneumonia (Cormier et al., 1990; Duchaine et al., 2000; May et al., 2012).

However, other factors also need to be considered in the case of risk of acute and chronic respiratory health effects, namely, individual genetic susceptibility to endotoxin or allergens, length of time the subject has worked, whether the individual smokes, whether subjects have other respiratory conditions, and the indoor concentration of contaminants. Several individuals may have adverse health effects within the first week of work, but most subjects do not develop symptoms unless they have worked more than 2 h/d and for 6 yr or more (Donham and Gustafson, 1982; Donham et al., 2000). The aim of this study was to characterize particulate matter (PM) contamination in seven Portuguese swine farms. In addition, this investigation assessed the existence of clinical symptoms associated with asthma and other allergic diseases in swine workers by applying the European Community Respiratory Health Survey questionnaire.

MATERIALS AND METHODS

Particulate Matter (PM) Measurement

Measurements were performed using a portable direct-reading equipment (Lighthouse, model 3016 IAQ) to measure five different sizes ($PM_{0.5}$, $PM_{1.0}$, $PM_{2.5}$, $PM_{5.0}$, PM_{10}). This option was chosen because differentiation between particle size fractions is important in order to estimate with more detail the possible penetration of dust into and within the respiratory system. The measurements were conducted near the workers' noses and during their presence in the buildings performing different tasks. In most of the swine farms, three or more measurements were taken and mean values were obtained for each particle size. All measurements were conducted continuously with a duration of 5 min. In all swine farms studied, workers did not use respiratory protection devices.

Questionnaire of Clinical Symptoms

Epidemiological data was analyzed by a validated questionnaire in Portugal from the European Community Respiratory Health Survey (ECRHS) (ECRHS, 2007). This survey enables determination of the prevalence of asthma and other allergic disease, the characterization of respiratory, skin, and eye symptoms, and estimation of work-related symptoms. Clinical data were obtained by cross-sectional study. The ECRHS questionnaire was completed by all subjects from case and control sample groups, applied in the form of interview. The case group included 33 swine workers and the control included 70 subjects without any type of agricultural activities (Table 1).

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TABLE 1. Gender Distribution of Studied Population

	Cases (*n* = 33)	Controls (*n* =70)
Male	17 (51.5%)	29 (41.4%)
Female	16 (48.5%)	41 (58.6%)

Statistical Analyses

Statistical analysis of all data was performed using the Statistical Package for Social Sciences (SPSS), version 21.0.

RESULTS

Particulate Matter (PM) Assessment

Data obtained showed higher particle concentration with PM_5 size and particles were predominantly PM_{10} (Table 2 and Figure 1). Figure 1 presents the distribution of particle size and shows that there is a similar trend in all swine farms, with high concentration of particles with PM_5 and PM_{10} size. With respect to PM contamination distribution, areas where fattening and quarantine occurred were the sites with higher levels (Figure 2).

Clinical Symptoms

Thirty-three workers were analyzed, with 16 (48.5%) women and 17 (51.5%) men. The prevalence of diagnosed asthma was 12.1%. All asthmatic workers were previously diagnosed with asthma, of which 50% reported the first attack after 40 yr of age. Clinical data on respiratory symptoms demonstrated a trend to higher prevalence for asthmatic (63.6%), nasal (45.4%), and skin (42.4%) symptoms in swine farm workers. In contrast, eye symptoms displayed a low prevalence.

TABLE 2. Mean Values of Particulate Matter Contamination per Swine (Values in mg/m^3)

Farm	PM0.5	PM1	PM2.5	PM5	PM10
A	0.008	0.013	0.046	0.439	2.212
B	0.020	0.044	0.186	1.270	5.289
C	0.003	0.009	0.079	0.968	5.091
D	0.003	0.008	0.046	0.459	2.039
E	0.023	0.043	0.116	0.604	1.913
F	0.001	0.008	0.067	0.684	3.122
G	0.004	0.007	0.037	0.435	2.250

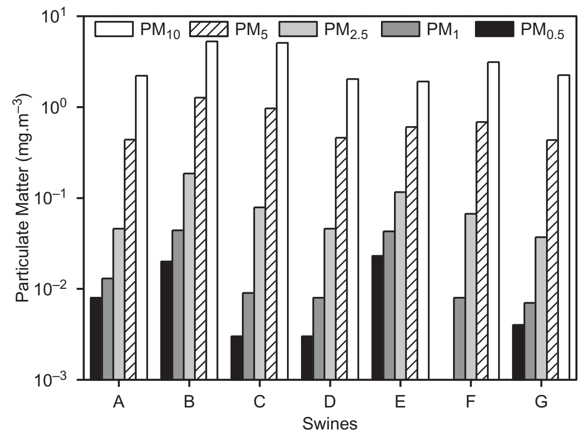

FIGURE 1. Distribution of particle matter by size in each farm.

A high prevalence of respiratory symptoms in workers without asthma was also observed, including wheezing (n = 10; 34.5%) and coughing (n = 12; 41.4%). Further, 28% (n = 7) of the workers reported problems with sneezing, runny nose, or stuffy nose without having a cold or flu and also without medical diagnosis of rhinitis. In this study, 6 workers (18.2%) reported having chest tightness or wheezing at work, which was reported to be directly associated with their involvement in specific activities in the workplace. In addition, 13 (39.4%) of all the participating workers indicated an improvement of their respiratory ability during the resting days and holidays, suggesting an association of respiratory disturbances with occupational activities. However, these results were not found to be statistically significant when comparing differences between individuals that displayed symptoms and those without. Nevertheless, it is important to note that there was a trend for increased frequency of upper and lower respiratory symptoms in subjects exposed to higher concentrations of PM. A tendency for those subjects with diagnosed asthma occurred when individuals were exposed to higher concentrations of PM with larger size ($PM_{2.5}$, PM_5, and PM_{10}). In contrast, in the case of sneezing, runny nose, or stuffy nose without having a cold or flu,

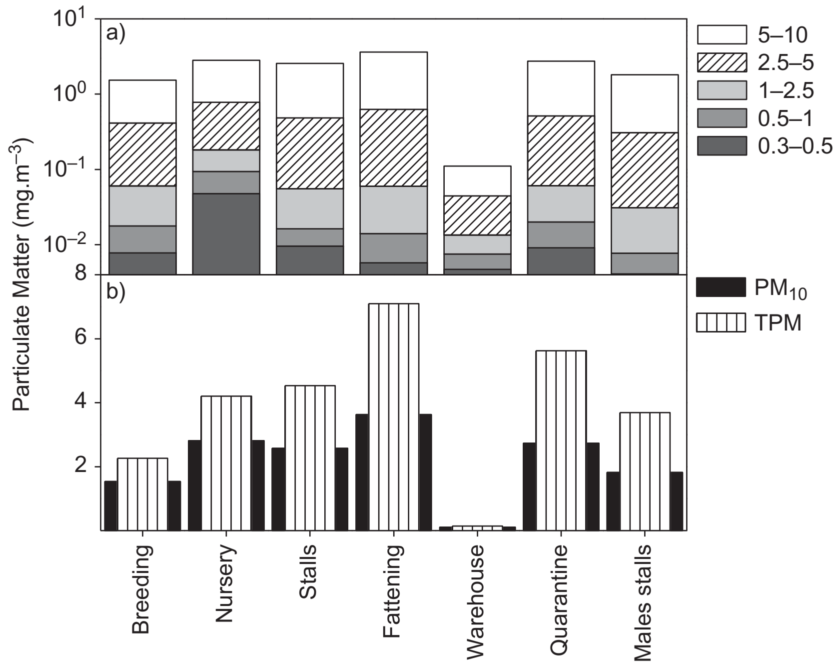

FIGURE 2. a) Particles distribution in different places by size; b) PM10 distribution in different places and total particulate matter (TPM="total dust"). Adopted from Viegas et al. (2013a).

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association following exposure to higher concentrations of PM with smaller size ($PM_{0.5}$ and PM_1) was found.

DISCUSSION

The majority of previous studies estimated PM exposure by dust concentration measurements and were often carried out by means of gravimetric systems, providing only information of total mass concentration obtained and separating data only into "total dust" and "respirable dust." Few studies on agricultural farms investigated the PM exposure with respect to particle size. Lee et al. (2006) demonstrated that PM size affects deposition in the respiratory system, possibly resulting in different adverse health effects. Recent studies noted the influence of different PM sizes on health effects, showing that coarse particulate induced macrophage inflammatory reactions to a greater extent than fine and ultrafine particulate matter (Alexis et al., 2006; Ghio et al., 2012; May et al., 2012). Data showed higher PM contamination in PM_5 size and predominantly PM_{10} (Table 2), indicating that swine dust penetrated into the gas exchange region of the lung (PM_5) and may also produce disease by impacting in the upper and larger airways below the vocal cords (PM_{10}) (Vincent and Mark, 1981).

Several studies demonstrated adverse respiratory health effects related to occupational exposure in intensive livestock houses (Kogevinas et al., 1999; Donham, 1999; Eduard et al., 2009; May et al., 2012; Harting et al., 2012). A correlation between environmental exposure in livestock buildings and deficient lung function changes and/or respiratory symptoms in workers was previously observed (Donham et al., 1989, 1995; Reynolds et al., 1996; Donham, 1999). These studies identified exposure-response thresholds for workers on the basis of thresholds established for swine confinement buildings. Previous dose-response studies with swine farm workers (Donham and Cumro, 1999) resulted in exposure limit recommendations of 2.4 mg/m^3 of total dust and 0.23 mg/m^3 of respirable dust (Pedersen et al., 2000). Moreover, Donham and colleagues (1989) reported that concentrations

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higher than 2.5 mg/m^3 were associated with higher frequency of symptoms of respiratory diseases. Our results showed values higher than these exposure limits recommendation, in some cases (Swine B and C) twofold higher (Table 2 and Figure 1). Further, comparing our results for total PM with limit recommendation defined by Donham and Cumro (1999), it is possible to observe in Figure 2b that in all assessed places this value was exceeded, with exception for Breeding and Warehouse.

A study developed by Basinas and colleagues (2013) in 53 Danish pig farms obtained a mean exposure level of 3.4 mg/m^3 for inhalable dust (comparable to size PM_{10}). Two of seven farms (Farms B and C) considered in our study obtained higher values (Figure 1), and these are related to the fact that there is only natural ventilation as ventilation source while other swine farms had a combination between natural and mechanical (exhaust) ventilation. The same trend in the results was obtained by Kim and colleagues (2008), where the concentrations and emissions of dust were higher in the naturally ventilated pig buildings.

Currently, there is little need for manual work in systems of pig production because most of the confinement pig houses are constructed with automation. In Portugal, however, there are some activities that still need farmer intervention, such as cutting piglet tails and vaccination. Because of that, there is an increase in the time spent in those places, and consequently increased exposure to PM (Viegas et al., 2013b).

There is no agreement in the literature regarding which is the swine production phase with higher concentration of PM. Data for PM_{10} are consistent with those of other investigators who suggested that dust concentrations are higher in fattening rooms than in nurseries (Figure 1b) (Harmon et al., 2012). Kirkhorn and Garry (2000) reported that dust levels are highest in finishing buildings, which are buildings where swine are located prior to going to market. In addition, Nonnenmann and colleagues (1989) showed a strong linear relationship between total weight of pigs in the room and the dust concentration. In that study, dust concentration more than doubled as the pigs grew. Therefore, the amount of animal mass is an important factor influencing dust concentration (Pedersen et al., 2000).

Data in Figure 2a show that the nursery presents the highest concentration of minor particles (0.3–0.5 μg). In these places pigs are on a special status condition, with mobility difficulties, which hampers the maintenance of the cells and, consequently, leads to accumulation and resuspension of fecal material, promoting exposure.

The inflammatory potential of PM is related to size and concentration, as well as the fact that PM may act as a carrier and a source of nutrients for fungi (such as *Aspergillus* spp., *Penicillium* spp., and *Mucor* spp) (Seedorf et al., 1998) and bacteria (Becker et al., 2002; Halstensen et al., 2013). Particulate matter is also rich in endotoxins from the cell walls of gram-negative bacteria (Mayeux, 1997), and some studies associated endotoxin levels in swine confinement structures with adverse respiratory health outcomes (Donham et al., 1995; Reynolds et al., 1996; Schwartz et al., 1995; Vogelzang et al., 1998; May et al., 2012). These biologically active compounds adhering to PM, along with coexisting toxicant gases, promote concern regarding exposure to mixtures and possible additive and synergistic health effects (Von Essen and Donham, 1999). Taking this into account, it becomes a challenge to distinguish and separate adverse effects of PM from and gases, as they occur simultaneously in this occupational setting (Kirkhorn and Garry, 2000).

Clinical symptom prevalence of asthma was detected in 12.1%, which is consistent with previously reported data for prevalence of asthma in the general population (10%) and farmer workers (7.7%) (Kogevinas et al., 1999; Bardana, 2003). In addition, the prevalence of self-reported symptoms was quite similar in swine farm workers and controls. However, the occurrence of asthma and of nasal and skin work-related symptoms in swine farm workers presented a higher prevalence compared to eye symptoms, which were expected due to continuous exposure to swine dust. A high

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prevalence of respiratory symptoms in workers without diagnosis of asthma or rhinitis was also observed, especially aggravated during occupational activities, suggesting an underestimation of respiratory symptoms associated with professional practice (Ayres et al., 2011) and a misinterpretation of the disease that is common in patients with this kind of respiratory problems (Global Initiative for Asthma [GINA], 2009; Loignon et al., 2009).

Two workers reported that their first asthma attack occurred after reaching 40 yr of age, suggesting the influence of the working activities in the development of disease. This fact supports the possibility that occupational activities of swine farm workers may have a negative influence on development of disease, suggesting the prevalence of occupational asthma of 6.1% to be consistent with other European studies (Kogevinas et al., 1999; Bardana, 2003).

Aerosol particles with a mean aerodynamic size below 10 μm are able to penetrate deeply into the human airways and promote adverse respiratory manifestations (Lauriere et al., 2008). The tendency for subjects with diagnosis of asthma being exposed to high concentrations of particles with larger size ($PM_{2.5}$, PM_5, and PM_{10}) and subjects withs sneezing, runny nose, or stuffy nose without having a cold or flu being exposed to high concentrations of particles with smaller size ($PM_{0.5}$ and PM_1) confirms that the spatial distribution of deposited particles is strongly affected by particle size (Darquenne, 2012). It is known that large particles (2–6 μm) are deposited in the central and small airways, promoting asthmatic symptomatology, and small particles (<2 μm) are deposited in the alveolar region or can be exhaled for the upper airway, promoting nasal symptomatology (Cairo and Pilbeam, 2004; Darquenne, 2012).

CONCLUSIONS

Results from the present study emphasize the need to invest in preventive and protective measures to avoid exposure to PM. Considering the risk noted due to the high exposure to PM and consequent symptoms probably related with this exposure, the implementation of specific programs that address respiratory health surveillance and protection is recommended.

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