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PARTICULATE MATTER CONCENTRATIONS AND EMISSIONS IN RABBIT FARMS

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Abstract: The extent of the potential health hazards of particulate matter (PM) inside rabbit farms and the magnitude of emission levels to the outside environment are still unknown, as data on PM concentrations and emissions in and from such buildings are scarce. The purpose of this study was to quantify airborne PM10 and PM2.5 (particulate matter which passes through a size-selective inlet with a 50% efficient cut-off at 10 µm aerodynamic diameter or at 2.5 µm aerodynamic diameter, respectively) concentrations and emissions on 2 rabbit farms in Mediterranean conditions and to identify the main factors related with farm activities influencing PM generation. Concentrations of PM10 and PM2.5 were determined continuously using a tapered element oscillating microbalance (TEOM) in one farm with fattening rabbits and one reproductive doe farm in autumn. At the same time as PM sampling, the time and type of human farm activity being performed was recorded. Additionally, temperature, relative humidity and ventilation rate were recorded continuously. Emissions were calculated using a mass balance on each farm. Results showed PM concentrations in these rabbit farms were low compared with the average values given for poultry and pig farms. Average PM10 concentrations were 0.08±0.06 (fattening rabbits), and 0.05±0.06 mg/m^3 (reproductive does). Average PM2.5 concentrations were 0.01±0.02 (fattening rabbits), and 0.01±0.04 mg/m^3 (reproductive does). Particulate matter concentrations were significantly influenced by the type of human farm activity conducted in the building rather than by animal activity. The main PM-generating activity in the fattening rabbit farm was sweeping, while the major PM-generating activity in reproductive doe farm was sweeping and burning hair from the cages. Average PM10 emissions were 6.0±6.1 (fattening rabbits), and 14.9±31.5 mg/place d (reproductive does). Average PM2.5 emissions were 0.2±1.3 (fattening rabbits), and 2.8±19.5 mg/place d (reproductive does). Emission results indicate that rabbit farms can be considered relevant point sources of PM emissions, comparable to other livestock species. Our results improve the knowledge on factors affecting concentration and emissions of PM in rabbit farms and can contribute to the design of suitable PM reduction measures to control not only PM inside rabbit houses, but also its emission into the atmosphere.

Key Words: rabbit, air quality, animal housing, atmospheric pollution, dust.

INTRODUCTION

Airborne particulate matter (PM) is abundant in the air of livestock houses (Takai *et al.*, 1998; Cambra-López *et al.*, 2010). High indoor concentrations of PM can compromise the respiratory health of animals and humans, causing detrimental effects on animal performance and efficiency (Donham and Leininger, 1984; Donham, 1991; Al Homidan and Robertson, 2003), and on the health and welfare of farmers (Donham *et al.*, 1984; Andersen *et al.*, 2004). Moreover, PM can be emitted to the outside environment through the ventilation exhausts (Phillips *et al.*,

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1998), threatening the environment (plants and organisms), causing vegetation stress and ecosystem alteration (Grantz *et al.*, 2003). Although PM concentrations and emissions have been characterised in poultry and pig production systems (Costa and Guarino, 2009; Lacey *et al.*, 2003), little is known about PM concentration and emissions in and from rabbit houses (Navarotto *et al.*, 1995; Ribikauskas *et al.*, 2010). Although PM concentrations in rabbit farms seem to be low compared to other livestock species (Cambra-López et al., 2008), the emission of PM into the atmosphere could be relevant due to the high ventilation rates observed in those European regions where rabbits are reared (typically Mediterranean countries) (Calvet et al., 2011).

Particulate matter in livestock facilities can originate from several sources such as manure, feed, feathers, skin and bedding material (Cambra-López *et al.*, 2011). The size of PM is one of the most relevant properties because it influences its behaviour in the air and in the respiratory tract. Therefore, PM is usually characterised in terms of its size, as regards the occupational health size fractions: inhalable, thoracic, and respirable (CEN, 1993). These fractions, moreover, can be related to the outside air quality cut-off sizes: PM10 and PM2.5 (particulate matter which passes through a size-selective inlet with a 50% efficient cut-off at 10 μm aerodynamic diameter or at 2.5 μm aerodynamic diameter, respectively), regulated in the Council Directive 1999/30/EC, relating to limit values for sulphur dioxide, nitrogen dioxide and oxides of nitrogen, PM and lead in ambient air. The PM10 fraction can be inhaled and accumulated in the upper respiratory airways. This fraction includes the smaller PM2.5 fraction, which can penetrate deeper into the respiratory airways and reach the alveoli in the lungs. Since livestock production can emit considerable amounts of PM into the atmosphere (Takai *et al.*, 1998), there is an increasing tendency to monitor PM10 and PM2.5 fractions instead of occupational health size fractions to comply with air quality regulations outside livestock houses (Directive 1999/30/EC and Directive 2008/50/EC).

To assess the extent of the potential health hazards of PM inside rabbit farms and the magnitude of emission levels to the outside environment, further research on PM concentrations and emissions is needed. Hence, enhancing the knowledge of factors affecting concentration and emissions of PM in rabbit farms is necessary to design adequate PM reduction measures to control PM. This would allow an improvement of the air quality inside the animal house, and the development of technically feasible, environmentally acceptable, and economically viable measures to reduce PM emissions into the atmosphere.

The aim of this study was to quantify airborne PM10 and PM2.5 concentrations and emissions in 2 rabbit farms in Mediterranean conditions and identify the main factors related with farm activities influencing PM generation.

MATERIAL AND METHODS

Housing and animals

Two rabbit farms were surveyed in this study: one rearing fattening rabbits and another rearing reproductive does. Animals were raised in cages on both farms. Manure was accumulated in pits below the cages for 3 to 4 wk.

Both farms were located in the region of Valencia (Eastern Spain) and were surveyed for 15 consecutive day on each farm during autumn. Table 1 describes both farms in terms of housing and animals.

Table 1: Description of the surveyed rabbit farms.

	Fattening rabbits	Reproductive does
Length×width (m)	30×6	30×11
Animal places	2100	530
Average animal weight (kg)	1300	4000 (including litter)
Feed distribution	Manually distributed pellets	Automatically distributed pellets
Ventilation	Tunnel mechanical 2 fans (Q^1=10131 m^3/h)	Transversal mechanical 7 fans (Q^1= 1762 m^3/h)

[1]Q= Fan average airflow rate. All fans were on/off operated.

Environmental parameters

Indoor and outdoor temperature and relative humidity were recorded every min using data loggers (HOBO H8-007-02, Onset Computer Corporation, Pocasset, MA., U.S.) in each rabbit farm.

Additionally, ventilation rates were continuously monitored. Ventilation rates were calculated considering the working time of each fan and the corresponding fan extraction rates, following Calvet *et al.* (2010). Direct measurements of fan activity and extraction capacity of each fan were taken. Fan activity (percentage of time each fan was functioning) was determined by means of a motor on/off sensor (HOBO H06-004-02, Onset Computer Corporation, Pocasset, MA., U.S.). The extraction capacity of each fan (fan airflow) was registered before and after each sampling period by multiplying the free flow area by the average air speed in each fan. Air speed was gauged at 24 points of the cross section of the fan using a hot wire anemometer (Testo® 425, Germany, measurement range 0 to 20 m/s). As a result, the global ventilation rate on each farm during measurement was calculated by multiplying the activity of each fan by its extraction capacity, and summarising for the total number of fans.

Particulate matter levels: concentration and emissions

Concentrations of PM10 and PM2.5 size fractions were simultaneously determined using a tapered element oscillating microbalance, TEOM (TEOM model 1405-D, Thermo Fisher Scientific, U.S.). This device operated on changes in the resonant frequency of an oscillating element as a function of increases in particle mass collected on a filter. Changes in the recorded resonant frequency of the element provide continuous and time-averaged measurement of mass accumulation. Filters were exchanged at approximately 50% loading, following Heber *et al.* (2006). The PM concentrations were recorded every min for both fractions over 15 consecutive days per farm. Average daily PM concentrations (mg/m^3) were calculated from these data.

The TEOM device was located indoors, close to the ventilation exhaust in each farm. Measurements were conducted at a height of 2 m. At the same time as PM concentrations were measured indoors, the time and type of activity being performed by workers on each farm was recorded. Activities varied daily but were repeated weekly. Routine activities included animal handling and supervision, mortality inspection, feed distribution, cleaning cages with pressurised water, cleaning cages by burning hair, application of powdered disinfectant on the floor (calcium superphosphate) and floor sweeping on all farms; as well as the preparation of nests using cotton waste as bedding material, and powdered sulphur as disinfectant, only in reproductive does farm.

The PM emissions were calculated using a mass balance on the farm, by subtracting the PM concentration measured outdoors (PM_1) from the concentration measured inside the rabbit farms

(PM_e) and multiplying it by the ventilation rate (Q_e) (equation 1). The emission rate according to equation 1 was calculated from the TEOM data provided at standard conditions (standard temperature, T_{std}=298.15 K and standard pressure, P_{std}= 1 atm), correcting for ambient temperature and barometric pressure (T_a and P_a) according to Li *et al.* (2008):

$$Emission = Q_e \times \left(PM_e - \frac{\rho_e}{\rho_i} PM_i \right) \times 10^{-6} \times \frac{T_{std}}{T_a} \times \frac{P_a}{P_{std}} \qquad \text{Equation 1}$$

where; *Emission:* emission rate (g/h), Q_e: ventilation rate (m^3/h), PM_i: inlet particulate matter concentration (µg/m^3), PM_e: exhaust particulate matter concentration (µg/m^3), ρ_e, ρ_i: exhaust and inlet air density (kg dry air/m^3 wet air), T_a: ambient temperature (K), P_a: ambient pressure (atm), T_{std}: standard temperature (298.15 K), P_{std}: standard pressure (1 atm).

Outdoor PM concentrations (PM_i) were obtained from the nearest air quality sampling station from the "Valencian Community atmospheric contamination surveillance and control monitoring networks" (RVVCCA; Generalitat Valenciana, 2009). The sampling station was located at approximately 400 m from the farms. This station recorded hourly PM10 and PM2.5 concentrations.

Finally, hourly emission rates (g/h) were summarised over 24-h periods, and divided by the number of animal places during the sampling period in each farm, to calculate daily emissions per animal (mg/place d).

Statistical analysis

Effects of type of activity on PM10 and PM2.5 concentrations for each animal type were analysed with 1-way ANOVA using SAS Software (SAS, 2001) with type of activity as the source of variance. Hourly PM10 and PM2.5 concentration values over the sampling period were the experimental unit in this ANOVA analysis. In addition, this analysis was repeated for specific days within the sampling period in fattening rabbits and reproductive does. Differences with *P*-values less than 0.05 were considered statistically significant.

Differences between fattening rabbits and reproductive does for average daily PM concentrations (mg/m^3) and emission rates (g/h) were determined with a 2-tailed t-test for 1 treatment with 2 levels (animal type) using SAS Software (SAS, 2001). Differences with *P*-values less than 0.05 were considered statistically significant.

RESULTS

Environmental parameters

Table 2 shows average (±standard deviation, SD) indoor and outdoor temperature and relative humidity during measurements in each farm. Ventilation rates varied from 8.6 to 12.3 m^3/h. Indoor and outdoor temperature ranged from 18 to 22°C, and relative humidity from 48 to 68%.

Table 2: Average ventilation rate, indoor and outdoor temperature (°C) and relative humidity (%) and standard deviation, in fattening rabbits and reproductive does farm.

Animal type	Ventilation rate (m^3/h)	Indoor temperature (°C)	Indoor RH[2](%)	Outdoor temperature (°C)	Outdoor RH[2](%)
Fattening rabbits	8.6±5.0	21.8±1.9	68.0±9.7	20.3±4.2	63.8±15.2
Reproductive does	12.3[1]	19.4±2.7	54.8±10.6	17.9±3.5	48.1±13.7

[1] All fans were running constantly. [2] RH: relative humidity.

Table 3: Average concentration of PM10 y PM2.5 (mg/m^3) and SD, in fattening rabbits and reproductive does farm.

Animal type	PM10 (mg/m^3)	*P*-value	PM2,5 (mg/m^3)	*P*-value
Fattening rabbits	0.082±0.059[a]	0.001	0.012±0.016	0.896
Reproductive does	0.048±0.058[b]		0.012±0.035	

[a,b]Averages within a column with different superscripts differ significantly (P<0.05).

PM concentrations

Average (±SD) concentrations of PM10 and PM2.5 in the air of the fattening rabbit and reproductive doe farms are shown in Table 3. Average PM10 concentrations were 2-fold higher (P<0.001) in fattening rabbits compared with concentrations in reproductive does. Average PM2.5 concentrations were similar on both farms. The proportion of PM2.5 in PM10 ranged from 15 to 25% on both farms.

Figures 1 and 2 show the evolution of the daily concentration of PM10 and PM2.5 in fattening rabbits and reproductive does, respectively, during the whole sampling period. The evolution of PM concentrations resulted in daily variations, showing isolated spikes followed by periods of low concentrations (below 0.1 mg/m^3). Figure 1 shows maximum spikes in PM10 concentration in fattening rabbits reached 0.9 mg/m^3, whereas maximum spikes in PM2.5 concentrations reached 0.3 mg/m^3. Figure 2 shows maximum spikes in PM10 concentration in reproductive does reached 0.8 mg/m^3, whereas maximum spikes in PM2.5 concentrations reached 0.6 mg/m^3 for PM2.5.

The relationship between the type of activity and PM10 and PM2.5 concentrations per farm showed differences between animal type and between PM size-fractions. In fattening rabbits, average PM10 concentrations were 3-fold higher (P<0.0001) during sweeping compared with when no recorded activity was performed (i.e. no routine activities took place because working hours were over). Average PM10 concentrations were 2-fold higher while burning the hair from the cages (P<0.001) and during animal handling or cleaning the cages with pressurised water (P<0.0001) compared with no recorded activity. Among all activities, sweeping was found to be the activity which generated the highest concentration of PM10. Average PM2.5 concentrations were 4 to 5-fold higher (P<0.0001) during sweeping, animal handling or cleaning the cages

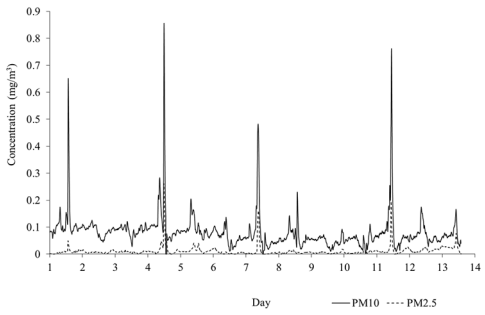

Figure 1: Daily PM10 and PM2.5 concentration within sampling period in fattening rabbits farm.

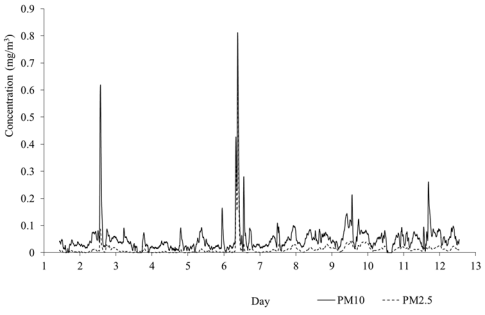

Figure 2: Daily PM10 and PM2.5 concentration within sampling period in reproductive does farm.

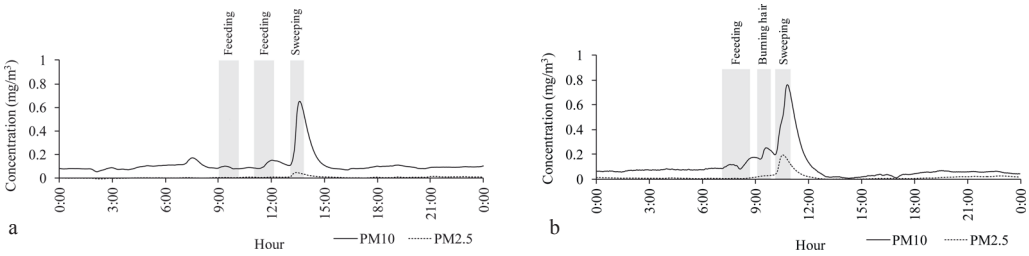

Figure 3: Hourly variation in PM10 and PM2.5 concentrations within 24 h periods for 1 d (a) and 11 d (b) of the sampling period, in fattening rabbits with farm routine farm activities.

with pressurised water, than when no recorded activity was performed. However, no statistical significant differences in PM2.5 concentrations among these activities were observed. Average concentrations of PM2.5 during sweeping, animal handling or cleaning the cages with pressurised water were 3 to 4-fold higher (P<0.001) than during feeding or burning the cage hair.

In reproductive does, average concentrations of PM10 were 4 to 5-fold higher (P<0.0001) during sweeping and burning cage hair, and 2-fold higher (P<0.05) during feeding, than when no recorded activity was performed. No statistical significant differences were found between sweeping and burning cage hair, but they were statistically significantly different from the other activities. Feeding and disinfecting were not statistically significantly different from each other, but PM10 concentrations during these activities were lower (P<0.05) than during sweeping and cage hair burning. Average PM2.5 concentrations were 10 to 12-fold higher (P<0.0001) during sweeping and burning the cage hair than when no recorded activity was performed. No differences between these 2 activities were found, but average PM2.5 concentrations during these activities were 4 to 6-fold higher (P<0.05) than during feeding and disinfecting.

As an example, Figure 3 shows hourly PM10 and PM2.5 concentrations measured in fattening rabbits during 2 different days (24 h), together with the activities within each day. Variations in PM concentrations coincided with the time when farm activities were carried out in the buildings. This figure corresponds to 1 d (Figure 3a) and 11 d (Figure 3b) of the whole sampling period shown in Figure 1. Indoor PM10 and PM2.5 concentrations were below 0.1 mg/m³ throughout the day, increasing between 07:00 to 15:00 h, coinciding with the hours of higher human activity inside the farm. On 1 and 11 d, PM10 and PM2.5 concentrations were the highest during sweeping (P<0.0001). Average PM concentrations were 4-fold higher (P<0.0001) for PM10, and from 5 to 20-fold higher (P<0.0001) for PM2.5, during sweeping than during feeding

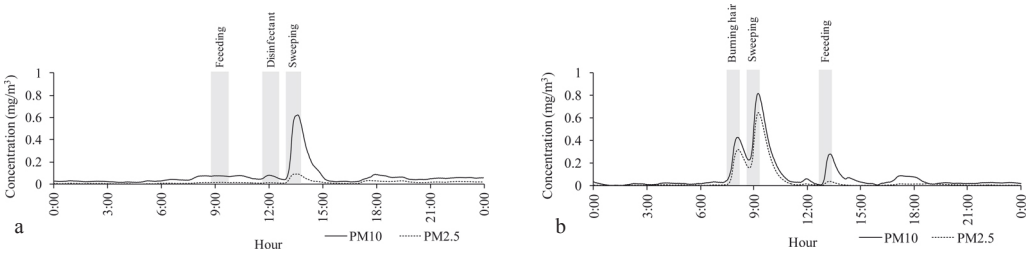

Figure 4: Hourly variation in PM10 and PM2.5 concentrations within 24 h periods for 2 d (a) and 6 d (b) of the sampling period, in reproductive does with routine farm activities.

Table 4: Average PM10 and PM2.5 emissions per hour (g/h), and standard deviation in fattening rabbits and reproductive does farm.

Animal type	PM10 (g/h)	*P*-value	PM10 (mg/place d)	PM2.5 (g/h)	*P*-value	PM2.5 (mg/place d)
Fattening rabbits	0.52±0.54[a]	0.008	5.99±6.14	0.02±0.11	0.278	0.20±1.26
Reproductive does	0.33±0.7[b]		14.85±31.47	0.06±0.43		2.83±19.54

[a,b]Averages within a column with different superscripts differ significantly ($P<0.05$).

or burning cage hair. After 15:00 h, concentrations remained low and more or less constant until the next day, at about 7:00 h.

Figure 4 shows an example of hourly PM10 and PM2.5 concentrations measured in reproductive does during 2 different d (24 h), together with the activities within each day. This figure corresponds to 2 d (Figure 4a) and 6 d (Figure 4b) of the whole sampling period shown in Figure 2. Indoor PM10 and PM2.5 concentrations also increased between 07:00 to 15:00 h, coinciding with the hours of higher human activity inside the farm, the same as for fattening rabbits. On 2 and 6 d, PM10 and PM2.5 concentrations were the highest during sweeping ($P<0.0001$). Average PM concentrations were 2 to 8 fold higher ($P<0.0001$) for PM10 and from 2 to 21 fold higher ($P<0.001$) for PM2.5 during sweeping than during feeding, burning cage hair or disinfecting. A similar trend as in fattening rabbits was observed in PM concentration evolution in time within a 24 h period.

PM emissions

Table 4 shows average (±SD) PM emission rates for fattening rabbits and reproductive does. Outdoor PM concentrations during measurements on both farms ranged from 0.002 to 0.113 mg/m^3 for PM10 and from 0.001 to 0.056 mg/m^3 for PM2.5. Average PM emission rates (g/h) were slightly higher in fattening rabbits compared to reproductive does. These differences were more pronounced for PM10 compared with PM2.5, as PM2.5 concentrations shown in Table 3 were overall low and similar between farms. Average emission rates per animal, place and day showed

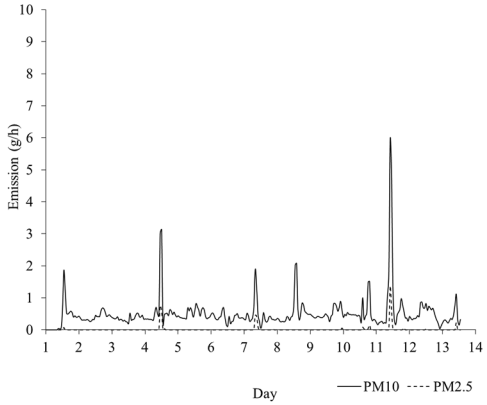

Figure 5: Daily PM10 and PM2.5 emission within sampling period in fattening rabbits farm.

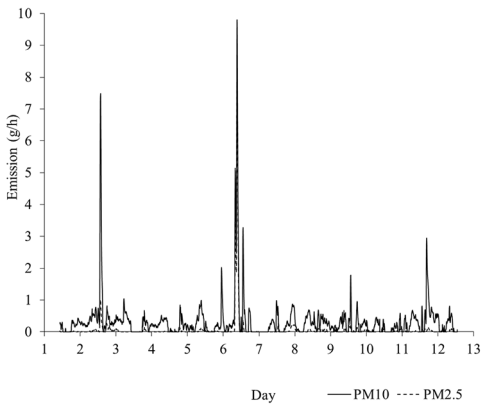

Figure 6: Daily PM10 and PM2.5 emission within sampling period in reproductive does farm.

emission rates were more than 2-fold higher in reproductive does, considering animal numbers were higher in fattening rabbits (2100 fattening rabbits) compared with reproductive does (530 does).

Figures 5 and 6 show daily emission variation of both PM10 and PM2.5 emissions in fattening rabbits and reproductive does, respectively. Daily variations in emissions corresponded with variations in indoor concentrations (Figure 1 and 2), which were furthermore related with human activities inside the farm. Consequently, peaks in PM emissions coincided with peaks in PM concentration. Figure 5 shows the emission of PM10 reached maximum values of 5.92 g/h and 1.36 g/h for PM2.5 in fattening rabbits. Figure 6 shows the emission of PM10 reached maximum values of 9.80 g/h and 8.04 g/h for PM2.5 in reproductive does.

DISCUSSION

Particulate matter is a highly relevant pollutant found in the air of confined livestock facilities. However, previous studies on air quality in rabbit farms have usually measured airborne pollutants other than PM, such as bioaerosols or gases (Duan *et al.*, 2006; Calvet *et al.*, 2011). Furthermore, to our knowledge, data on PM emissions from rabbit farms are limited, so our findings help fill this gap through the characterisation of concentrations and emissions of size-fractioned PM2.5 and PM10.

Particulate matter concentrations presented herein resulted in higher PM concentrations in fattening rabbit farms compared with reproductive does, but were overall low compared to other livestock species and regulation thresholds. Airborne PM concentrations in both rabbit farms were below occupational thresholds according to human health (HSE, 2007) and below maximum exposure recommendations for livestock. Although no limits have been established as regards PM concentrations and rabbit health, concentrations did not exceed the recommended swine health limits of 3.7 mg/m^3 for inhalable PM (particles which can be inhaled through the nose and mouth) and of 0.23 mg/m^3 for respirable PM (particles which can go beyond the larynx and penetrate into the non-ciliated respiratory system) (CIGR, 1994).

Measured PM concentrations were below reported values for other livestock housing systems such as poultry or swine in the literature, which range from 0.05 to 15.30 mg/m^3 inhalable PM, and from 0.03 to 1.90 mg/m^3 respirable PM, as reviewed in Cambra-López *et al.* (2010). These differences among species are attributable to the peculiarities of rabbit production systems, where animals are reared in cages with limited movement and use no bedding material, which can be a relevant source of PM. This could result in less generation of PM, less deposition of PM on surfaces, and consequently less PM becoming airborne compared with swine or poultry (especially broiler) production systems. The use of deep pit manure collection in rabbit houses could also influence such low PM concentrations compared to swine or poultry housings, where animals are directly in contact with dried manure. Contact with dry manure could facilitate dried manure disintegration and its release into the air.

Although few studies have researched and quantified PM in rabbit farms, work by Kaliste *et al.* (2002) reported inhalable PM concentrations in laboratory rabbit rooms in the same range as PM10 in this study. Navarotto *et al.* (1995) reported inhalable PM concentrations to be in the range between 0.10 to 2.55 mg/m^3, and from 0.03 to 0.57 mg/m^3 for respirable PM, in an intensive fattening rabbit farm. Sancilio *et al.* (1999) reported inhalable PM concentrations to be in the range between 0.75 to 3.62 mg/m^3, and from 0.24 to 0.90 mg/m^3 for the respirable fraction. Nevertheless, Ribikauskas *et al.* (2010) reported higher concentrations for inhalable PM for

rabbits kept in groups in straw pens than those reported for size-fractioned PM for rabbits kept in cages in our study. Although direct comparison between occupational health size fractions and PM10 and PM2.5 is not straightforward because it depends on sampling instrument cut-off curves and the sampling conventions followed, our results for PM concentrations are found within the lower ranges of the values reported in the literature for occupational health size fractions. This could likely be a consequence of high ventilation rates experienced during the sampling period in our study, which result in a high dilution of indoor air and thus low airborne concentrations.

Among the physical and biological factors affecting PM concentrations in livestock farms, animal species, kind of housing system and environmental factors have been identified as some of the major factors influencing PM concentrations and emissions (Cambra-López *et al.*, 2010). PM concentrations in our study were directly affected by the time of day, increasing from 07:00 to 15:00 h. Rabbits have been reported to be more active at night (Estellés *et al.*, 2010) and Ribikauskas *et al.* (2010) also reported that air quality parameters were related to rabbit activity, except for PM concentrations. Our results showed that during 24-h measurements, peaks in PM concentrations were mainly related with human activity rather than animal activity. Sancilio *et al.* (1999) reported that burning hair on the cages through "flame cleansing" was a relevant activity as regards PM generation. Our findings indicated that sweeping in fattening rabbits and both sweeping and burning cage hair in reproductive does were related with the highest increases of PM10 and of PM2.5 concentrations.

Particulate matter emission rates in rabbit farms were influenced by PM concentration and routine farm activities. These findings can contribute to quantifying PM from livestock production systems. Emission rates expressed per animal place were lower compared with poultry, swine or cattle (Wathes *et al.*, 1997; Takai *et al.*, 1998; Lacey *et al.*, 2003). For instance, average emissions in broiler houses have been reported to be between 13 and 47 mg/animal d for PM10 (Lacey *et al.*, 2003; Roumeliotis and Van Heyst, 2007; Calvet *et al.*, 2009), and between 2.8 and 3.8 mg/animal d for PM2.5 (Roumeliotis and Van Heyst, 2007; Cambra-López *et al.*, 2009). Concentrations in broiler houses in these studies, however, were approximately 10-fold higher than in rabbit farms in our study. The emission rates obtained in this work are thus relatively high compared with other studies, taking into account the low concentrations measured in both rabbit farms. This imbalance can be explained by the high ventilation rates recorded during our experiment, in autumn in the Mediterranean area of Spain, compared with other regions. Therefore, the consequences and fate of PM emissions from rabbit farms to the external environment in these conditions must be taken into account and PM emissions from such houses should not be neglected.

The results presented in this study for 15 d of continuous monitoring are a valuable estimation for PM10 and PM2.5 emission factor for rabbit farms in Mediterranean conditions during autumn. Extrapolation of these results to a different season, however, should be done with caution, as ventilation rates and indoor and outdoor environmental parameters can vary notably within seasons. The ventilation rate in summer is higher than in autumn and indoor relative humidity can also be expected to be lower. On the contrary, in winter ventilation rates are lower than in summer and indoor relative humidity can also increase. Further research is therefore needed to compare these results with other periods of the year in rabbit farms.

Overall, the results presented in this study provide necessary data on air quality in rabbit farms, essential to understand and characterise PM concentrations and emissions in these animal facilities. Although PM concentrations inside rabbit farms are clearly below the threshold for human health, the effect that PM chemical and biological composition may have on human

or animal health and performance are still unknown. Nevertheless, our results improve the knowledge on the levels of PM in rabbit farms, which may be useful to identify factors affecting concentration and emissions and design suitable PM reduction measures to control PM not only inside rabbit houses, but also emissions into the atmosphere.

CONCLUSIONS

From our results, it can be concluded that:

Particulate matter concentrations inside rabbit farms are low compared with average values given for poultry and swine farms. Average PM10 concentrations measured in this study were 0.08±0.06 mg/m^3 in fattening rabbits and 0.05±0.06 mg/m^3 in reproductive does. Average PM2.5 concentrations were 0.01±0.02 mg/m^3 in fattening rabbits, and 0.01±0.04 mg/m^3 in reproductive does.

Particulate matter concentrations were significantly influenced by type of human farm activity performed in the building rather than by animal activity. Major PM-generating activity in fattening rabbit farm was sweeping while major PM-generating activity in reproductive does was sweeping and burning hair from the cages.

Emissions of PM from rabbit farms are comparable to other livestock species and should not be neglected. Average calculated PM10 emissions in this study were 6.0±6.1 mg/place d in fattening rabbits and 14.9±31.5 mg/place d in reproductive does. Average PM2.5 emissions were 0.2±1.3 mg/place d in fattening rabbits and 2.8±19.5 mg/place d in reproductive does.

These results improve the knowledge on factors affecting concentration and emissions of PM in rabbit farms and can contribute to designing adequate PM reduction measures to control PM not only inside rabbit houses, but also emissions into the atmosphere.

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