AMMONIA FROM FATTENERS PREVIOUSLY HOUSED IN DIFFERENT WEANING ROOMS

Annamaria Costa

Department of Health, Animal Science and Food Safety
Faculty of Veterinary Medicine
Università degli Studi di Milano
Tel 0039.02.50317904
Fax 0039.02.50317919
via Celoria 10, 20133 Milan, Italy

Corresponding author: annamaria.costa@unimi.it

Abstract

The aim of this study was to measure ammonia concentrations and emissions from finishing pigs housed in identical Best Available Techniques (BAT) room type (full floor with external dunging area) originating from different BAT weaning room types (full floor with external dunging area or slatted floor with vacuum system removal) in Northern Italy. The 1600 pigs utilized in the study came from different enclosed animal confinement: weanling slatted floors (WSF) or weanling concrete floors (WCF). In the WSF facility 800 weanling pigs were housed on slatted floor. The two rooms had the vacuum system for prompt manure removal. The WCF facility contained 800 pigs in rooms with a solid concrete floor and a fully-slatted external alley with a storage pit underneath. Pigs were blocked by their origin and allocated in 2 finishing rooms per group, each room had a solid concrete floor and fully-slatted external alley with a storage pit underneath, similar to the WCF growing facility. Ammonia concentration was greater in the WSF finishing buildings (5.31 vs. 7.45 mg m^{-3}, $P<0.001$), similar to the degree of fouling on the floor (37% vs. 77%, $P<0.001$). The WCF pigs produced 4.63 g pig^{-1} ammonia (NH_3) and WSF pigs produced 6.55 g pig^{-1} NH_3 during the 8 h of daytime measurements.

The different fouling degree produced by the animals of the two groups affected significantly the ammonia levels. Significantly lower animal performance of WSF pigs compared to the WCF pigs was observed although the pigs were housed in the same finishing facilities.

Keywords: Growers facilities, finishing pig facilities, Best Available Techniques, Ammonia

1. Introduction

Ammonia (NH_3) in livestock confinements, at high concentration levels, can be detrimental to animal and human health and welfare. Ammonia is produced by urine and feces decomposition and can be emitted from animal houses into the atmosphere via the ventilation systems. It is of great environmental concern because it contributes to soil acidification and increased nitrogen deposition in ecosystems (Pain et al, 1998). The noxious action of ammonia on livestock is widely reported in literature. As early as 1965, Day et al. demonstrated that pigs reared in enclosed facilities with underfloor waste pits have depressed rate of gain and that the incidence and severity of pneumonic lesions in pigs have been related to the air pollutant levels (Kovacs et al., 1967).

Drummond et al. (1980) found that aerial ammonia decreased young pigs' (8 weeks of age) growth. Percentage reductions from controls in average daily gain were 12%, 30% and 29% for 50, 100 and 150 ppm exposed groups, respectively.

It is possible growth depression is a consequence of reduced feed intake or reduced efficiency in nutrient utilization due to a state of general discomfort or sickness caused by ammonia. The concentrations measured in most experimental studies performed in swine facilities exceeded the recommended 7 ppm value (Donham, 1991, 1995; Heederick, 1997; Gustin et al., 1994).

In 1996, the European Union inacted Directive EU96/ 61/EC ,which is also known as "Integrated Prevention and Pollution Control" (IPPC). The purpose of the IPPC was to reduce NH_3 emissions into the atmosphere by defining the obligations of industrial and agricultural activities with high pollution potential.

New or existing industrial and agricultural activities, with a high pollution potential are defined in Annex I of this directive and include energy activities, production and processing of metals, mineral industry, chemical industry, management waste and animal husbandry. The IPPC Directive established a procedure for authorization and fixed the minimum requirements with regard to pollutant emissions to air, water and soil, to achieve a higher level of environmental protection. This directive compels the application of an Environmental Integrated Permit that covers all forms of emission into the environment and it must be followed by large farms with more than 40,000 poultry, or 2,000 finishing pigs heavier than 30 kg or 750 sows. Specifically, this directive prevents or limits ammonia emissions using sustainable and economic technologies.

In 2003, a panel of specialists of the European Commission published the "Integrated Pollution Prevention and Control (IPPC) Reference Document on Best Available Techniques (BAT) for Intensive Rearing of Poultry and Pigs" to describe the best available technologies for pig and poultry production, to address ammonia emissions into the atmosphere.

The term 'best available techniques' is defined in the IPPC as 'the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing, in principle, the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole' (Article 2, Definition 11). BAT are large scale developed techniques, economically sustainable, designed to guarantee a high general level of protection of the environment as a whole.

In the ILF-BREF manual (2003), the ability of the enclosed facilities for sows, growing and finishing pigs to reduce ammonia emission are compared with the traditional ones (Loyon et al., 2016). One of the most reliable solutions to reduce ammonia emission for growing-finishing pigs and sows facilities, is the adoption of the *vacuum system*, a technique in which pigs are housed on fully slatted floor and where the manure collected in the underneath pit is promptly removed to the storage tank. This technique can induce an ammonia reduction by 25 % and it is widely used in the confinement swine facilities of Northern Italy (Costa et al., 2009a).

Producers, despite the facilities adaptation to BAT standards, have repeatedly observed different fouling degree on the floor, depending on the different excretory behaviour of pigs reared in different post-weaning facilities.

Therefore the purpose of the study was to measure ammonia concentrations and emissions from finishing pigs housed in identical BAT room type (full floor with external dunging area) originating from different BAT weaning room types (full floor with external dunging area or slatted floor with vacuum system removal) in Northern Italy. Specifically the aim was to evaluate the relation between degree of fouled floor, ammonia emission, and animal performance.

2. Materials and Methods

2.1 Animals and buildings

The research trial was conducted in Northern Italy, from May to July 2014, using 1600 pigs of the same genetic characteristics (Landrace × Large White × Duroc) and of the same age.

Eight hundred finishing pigs utilized in the trial were raised in a WSF growing facility (ILF BREF, BAT n° 4.6.1.1) and the other 800 finishing pigs were raised in a WCF growing facility (ILF BREF, BAT n° 4.6.1.4). In the WSF growing facility, the pit underneath the whole room was 0.6 m deep; slats were of rectangular shape, 50 mm large and 1 m long, the gap between slats was 14 mm. Pigs, whose initial mean weight was 7.5 kg ± 0.78 kg, were housed in their respective growing facilities from 28 - 95 days of age. The two housing types adopted in the growing and in the finishing phase are shown in Fig 1.

At the end of the growing phase, at d 95 of pigs age, all the 1600 piglets were moved to four identical finishing rooms (2 rooms for each treatment group) and housed according to their original distribution in the growing rooms, to avoid mixing groups of animals. The finishing pigs remained in these rooms until 105 kg (185 d of age) when they were moved to another facility to reach market weight of 160 kg.

The four finishing buildings had identical dimensions, ventilation system, feeding type and feed administration, floor type and manure removal. The floor was full concrete, and the pigs had an external dunging area. The manure pit (0.8 m deep) underneath the external alley was 0.6 m large and equipped with triangular concrete slats 80 mm wide, with 18 mm gaps. Each finishing room was 17 m × 25 m and was divided in 12 pens arranged in two rows of 6 identical pens. There was a 1 m aisle to allow inspection and handling of the pigs by the operators, and the introduction of the movable scale for individual weighing.

Figure 1. Growing and finishing pig facilities used in the trial

The ventilation system of each building was equipped with inlets, located on the side walls, which provided fresh air, while the exhaust air was extracted from the three chimneys placed longitudinally on the ridge of the roof.

The maximum ventilation rate for the three chimneys (FANCOM EasyFlow, Panningen, The Netherlands) was 16352 m^3 h^{-1}. Inlets were equipped with sensors to move the opening angle according to inside temperature that was monitored through probes placed at the height of 1.2 m. The climate control system was governed by FCRA Fancom units and worked according to the ventilation control system (FANCOM) based on a free running impellers for each room, for continuous, real-time monitoring of the ventilation rate. The air exhausts were equipped with a calibrated ventilation rate sensor which had a measurement error of 45 m^3 h^{-1} (Berckmans et al., 1991).

The liquid feeding system delivered feed to the trough twice daily. The components of the diet, on dry matter basis, were soybean meal (40 %), barley (20 %), bran (19 %), wheat (10 %), fat (5 %) and microelements and vitamins (6 %). Water was provided *ad libitum* through nipples.

2.2 Evaluation of manure and urine on the floors: mapping the fouling

To determine excretory habits acquired by the pigs during the growing phase, the fouling degree assessment was performed during the weanling phase (28-95 d of age) and in the finishing phase (96-185 d of age). The amount of fouling of the solid pen floor with urine and manure was assessed visually one day per week in the 4 fattening rooms, each time ammonia was measured (see section 2.3). A map (scale 100:1) of the fouled area was drawn on paper. The wetted and fouled area was determined as percentage of the floor of the pen, subdivided in 3 sub-zones on paper (see Figure 2).

Figure 2. Ammonia concentration sampling points in the finishing facilities (A to G, 1, 2 and 3 are the zones of the pens subdivided for the visual observation of fouling on the floor).

2.3 Ammonia concentration measurements

During the three months of experimental study, ammonia concentration was measured in the finishing units (2 WSF and 2 WCF rooms) once per hour for 8 hours, one day per week, from 9 AM to 5 PM, for a total of nine measurements per location per room and 63 measurements per each room during each monitoring day. Ammonia concentration was measured (GasBAdge Pro Ammonia, Industrial Scientific, Pittsburgh, PA, USA, accuracy ± 5 %) in each room at 7 locations shown in the Figure 2 (A, B, C, D, E, F, G) to obtain information about the air quality in the pens and in the aisle. Sampling was carried out at 1 m of height, a compromise between animal and human's height.

2.4 Calculation of ammonia emission

Emission rate was calculated as the product of ammonia concentration for the ventilation rate, as reported in Eq. (1).

$$E_i = C_i \times V_i \qquad \text{Eq. 1 (Costa et al., 2009a)}$$

where E_i =pollutant emission at time i,

C_i = pollutant concentration at time i,

V_i = ventilation rate at time i,

i = time in minute of monitored parameter.

The error of the pollutant emission factor (δE) is limited by the sum of the errors of the pollutant's concentration measurement (δC) and the ventilation rate measurement (δV), Equation 2.

$$\delta E = \delta C + \delta V \qquad \text{Eq. 2 (Costa et al., 2009a)}$$

2.5 Other monitored parameters:

The live weights of pigs (LW), and their average daily gain (ADG) were recorded. All the animals were weighed at the beginning and end of the finishing phase. Moreover, 5% of the animals, randomly chosen, of each group were weighed individually, at d 30 and d 60 of the finishing cycle.

2.6 Statistical analysis

Data were submitted to variance analysis (Proc GLM of SAS statistical package, SAS 9.4, 2015) to test the effect of the two different adopted housing system (WSF vs. WCF) during the growing phase on degree of floors fouling, daily ammonia concentration and emission, and animal performance (LW and ADG).

The model contained the effects of treatment and time of measurement, and their interaction, random effect of the facility within facility type, and residual error. The initial weight of animals was used as a covariate in the model.

3. Results

3.1 Microclimatic conditions during the trial

Table 1 reports the microclimatic conditions measured inside and outside the rooms. Inside the buildings, the temperatures were high and out of the comfort zone for finishing pigs housed on concrete full floor (14°C - 24 °C). Relative humidity was in the optimal range (60-80 %). No significant differences were detected between the two types of rooms, and within rooms.

Table 1. Microclimatic parameters inside and outside the facilities

3.2 Fouling and ammonia in the two room types

During the weaning phase, 35% of the floor was fouled in the WCF rooms and 70% in WSF rooms. In general, in both facilities, piglets urinated and defecated in the back part of the pens, preferring humid and inadequately ventilated zones of the floor. Table 2 shows the overall mean concentrations, emissions of ammonia and level of fouling on the floor surface, in the fattening rooms.

The overall mean concentration of ammonia in our study were lower than the maximum acceptable concentrations recommended by the American Conference of Governmental Industrial Hygienists (ACGIH). Ammonia concentration was greater in the

WSF finishing facility than in the WCF facility (5.31 mg m^{-3} vs. 7.45 mg m^{-3}, P<0.001) and corresponded to an increase in the fouling degree on the floor (37% vs. 77%, respectively for the WCF and WSF pens; P<0.001). The interaction facility × time, initially included in the model, resulted not significant. Ammonia concentrations and emissions increased in the last month in a significant way in both facilities relative to the first two months of the study (P<0.001). this was likely caused by the increased amount of manure on the floor surface and for the continuous turning of the manure as the pigs walked on the fouled surface. This contributed to the increase in ammonia level. Figure 3 shows ammonia concentrations and emissions measured during the three months of finishing phase. Values were higher in WSF rooms (P<0.001) during all the experimental period.

Table 2. Ammonia concentrations and emissions, percentage of manure on the floor in the WCF (finishing barn housing pigs raised on full concrete floor during the growing phase) and WSF (finishing barn housing pigs raised on slatted floor during the growing phase) facilities.

Figure 3. Ammonia concentration and emission in the three months of the finishing phase in the WCF (finishing barn housing pigs raised on full concrete floor during the growing phase) and WSF (finishing barn housing pigs raised on slatted floor during the growing phase) facilities.

3.3 Animals performance: Live Weights and Average Daily Gain

At the beginning of the finishing phase, WCF pigs had an average LW of 35.70 kg and WSF pigs weighed 36.10 kg. At the end of the finishing phase, as, WCF pigs weighed 106.99 kg and WSF pigs 102.80 kg (P<0.001). As shown in Figure 4, WCF pigs were heavier than WSF pigs during the whole trial (P<0.001).

Pigs housed in WCF facilities gained 800 g, 860 g and 720 g, while WSF gained 680 g, 810 g and 730 g, during the three months of trial. There was a significant overall mean difference between the ADG in the two groups (P <0.05), as at the first and second month, with better performance for the WCF pigs during the whole cycle.

The reduced average daily gain in the last part of the finishing phase was due to the decline of water, ashes and proteins deposition in pig body, and, at the same time, to the decrease in the rate of lipid deposition, occurring at this pig age.

Figure 4. LW and ADG of finishing pigs in the WCF (finishing barn housing pigs raised on full concrete floor during the growing phase) and WSF (finishing barn housing pigs raised on slatted floor during the growing phase) facilities.

4. Discussion

This trial was entirely performed in pigs BAT facilities. Piglets reared in different growing BAT facilities developed a different habit in fouling that was maintained in the finishing pens.

Pigs that were weaned into WSF facilities had no access to an external dunging area, and therefore, developed a habit of defecating and urinating in the most humid, poorly ventilated zones of the pens (Costa et al., 2009b). This habit was carried over in the finishing barn, despite the availability of an external alley.

Results indicate a moderate pollution level in the finishing facilities. However, these concentrations may be slightly inflated because the measurements of ammonia concentrations were collected from 9 AM to 5 PM, when animal activity and ventilation rate were greatest. Our data are similar to those reported by other researchers. Ammonia concentrations of 3 to12 mg m^{-3} (Koerkamp P.W.G. et al, 1998), 12 to 30 mg m^{-3} (Demmers et al., 1999), 6.26 to 10.43 mg m^{-3} (Seedorf and Hartung, 1999) have been reported in the literature. In mechanically ventilated finishing facilities, Zhu et al. (2000) reported 2 to 6 mg m^{-3} of ammonia, Ni et al. (2000) reported up to 10 mg m^{-3}, Jacobson et al. (2003) measured 20.86 mg m^{-3} and Heber et al. (2005) reported 25.73 mg m^{-3} ammonia. A wide variability in ammonia concentration from livestock houses is evident in the literature. This variation can be affected by ventilation rate (Gustaffsson, 1997), relative humidity, animal density, the degree of manure and urine on the floor, and the type of floor and pit underneath (Fabbri et al., 2006, Aarnink et al, 1995 and 1996, Blanes Vidal et al., 2007, Arogo, 2003).

The WSF and the WCF facilities are capable of lowering ammonia emission by 25% and 20 – 40 % respectively compared to a traditional growing facility with a slatted floor and a pit underneath which produces 3 kg pig^{-1} y^{-1} ammonia.

The WCF pigs produced 4.63 g pig^{-1} of ammonia during the 8 hours of daytime and WSF pigs produced 6.55 g pig^{-1} during the 8 hours of daytime. No data are available in literature for comparison, of ammonia emissions from the WCF system. However we measured higher emissions than those indicated by the ILF BREF (2003) for this BAT (1.8 – 2.4 kg pig^{-1} y^{-1} ammonia, or 4.9 – 6.57 g pig^{-1} d^{-1} ammonia), partly because our measurements were collected in the daytime: Blanes Vidal et al. (2008) reported that overnight ammonia emission values were lower by 30% in comparison with daily values. Aarnink et al. (1995) measured 7% higher daily ammonia emissions from 8 AM to 6 PM in finishing pigs (5.69 compared 5.87 g/d /pig). This day-night variation in ammonia emission is linked to the greatest animal activity (Costa et al., 2012a, 2012b) during the day, and to the excretory behaviour of the pigs, which also shows a diurnal variation, with peaks in the daytime (Aarnink et al., 1995; 1996; Jeppsson, 2002). Even considering these aspect, our emission values, collected during the daytime, were unexpectedly higher than those estimated for this kind of BAT facility, in WCF and WSF rooms, probably since the BAT emission values reported in the ILF BREF (2003) were estimated considering this structural solution (inside and outside of the building, that is the dunging area) as a partly slatted floor (personal communication from CRPA, 2016).

Nevertheless, the ammonia emissions and degree of fouling on the floor, indicate that the air quality were significantly different in the two BAT finishing facilities. During the growing phase, pigs developed different excretory habits which were carried over into the finishing phase, affecting fouling patterns on the floor of the finishing facility. In fact, it is not unusual that pigs raised in partially outdoor systems are trained by showers to dung only a part of the pen Despite similar environmental conditions during the finishing phase of production, pigs reared in the WSF growing facility had significantly lower performance than pigs reared in the WCF growing facility. This reduction in performance may be linked to higher ammonia concentration in the finishing facility housing the WSF-reared pigs. Previous studies have demonstrated a decrease in animal productive performance correlated to high ammonia concentrations (Cargill, 2002; Gustaffsson et al., 2013) since ammonia can exert deleterious effects on the behavior, physiology, incidence of pathologies and productivity of the animals (Jones et al., 1996 and 2001). Moreover, generally speaking, ammonia produces negative effects on the olfactory systems of animals, increasing susceptibility to infection by reducing the rate of bacterial clearance from the respiratory tract (Dalhamn and Rhodin, 1956; Stombaugh et al., 1969), thereby leading to pneumonia and atrophic rhinitis (Stombaugh et al., 1969; Gustin et al., 1994; Urbain et al., 1994; Hamilton et al., 1996).

It can be concluded that since pigs fouling behavior is established in the growing phase, the finishing phase should be carried over in a similar facility to maintain the ammonia reduction provided by BAT systems. In this specific case, growers housed in a BAT facility with slatted floor exhibited the same defecating and urinating habits when moved to the BAT finishing facility with full floor, despite the availability of an external alley.

This management choice limited the barn capability to lower ammonia emission, affecting negatively animal performance.

5. Conclusions

- Air quality was significantly different in two identical rearing livestock housing, marked as BAT solution
- Concentrations of ammonia gas in the two room types were lower than 20 ppm indicated as acceptable by the American Conference of Governmental Industrial Hygienists (ACGIH), but ammonia level for the two groups of finishing showed significant differences according the previous weaning rearing BAT technique.
- The degree of fouling in the finishing facility was dependent on the excretory habits of the animals learned in the weaning facility.

- The better air quality may have contributed to improved daily gain of the WCF group compared to the WSF group of pigs.
- The correct moving of animals to the various compartments , during the whole production cycle, has a fundamental role in swine farming to prevent ammonia pollution, even in BAT systems.

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Month	**Overall means of inside temperature of WSF Pigs buildings (°C ± St. Dev.)**	**Overall means of inside temperature of WCF Pigs buildings (°C ± St. Dev.)**	**Overall means of relative humidity of WSF Pigs buildings (% ± St. Dev)**	**Overall means of relative humidity of WCF Pigs buildings (% ± St. Dev)**	**Overall means of ventilation rate of WCF Pigs buildings (m3/h per animal ± St. Dev)**	**Overall means of ventilation rate of WCF Pigs buildings (m3/h per anima ± St. Dev l)**	**External Temperature (°C ± St. Dev)**	**External RH (% ± St. Dev)**
May	24.6 ± 2.8	24.0 ± 3.1	72 ± 15	67 ± 15	96.45 ± 25.41	94.35 ± 23.52	19.74 ± 163	70 ± 13
June	28.0 ± 3.2	28.9 ± 3.4	79 ± 14	78 ± 16	107.55 ± 29.76	108.66± 27.86	23.29 ± 1.69	62 ± 13
July	29.44 ± 3.5	28.95 ± 2.8	58 ± 9	62 ± 7	119.85 ± 26.54	118.80 ± 23.43	22.34 ± 1.75	59 ± 13

Table 1. Microclimatic parameters inside and outside the rooms

	Overall lsmeans of ammonia concentration (mg m^{-3})	Overall lsmeans of ammonia emission (mg h^{-1} animal^{-1})	Overall lsmeans of fouled wet surface in the fattening buildings (%)
WCF PIGS	5.31 ±1.01A	579.20 ± 169.33A	37± 7.51 A
WSF PIGS	7.45 ±2.96B	819.36 ± 411.40 B	77.33 ±17.79 B

Table 2. Ammonia concentrations and emissions, percentage of manure on the floor in the WCF (finishing barn housing pigs raised on full concrete floor during the growing phase) and WSF (finishing barn housing pigs raised on slatted floor during the growing phase) facilities.

Values in the same column with superscript ($^{A, B}$) differ for $P < 0.001$

Month	**Overall means of inside temperature of WSF Pigs buildings (°C ± St. Dev.)**	**Overall means of inside temperature of WCF Pigs buildings (°C ± St. Dev.)**	**Overall means of relative humidity of WSF Pigs buildings (% ± St. Dev)**	**Overall means of relative humidity of WCF Pigs buildings (% ± St. Dev)**	**Overall means of ventilation rate of WCF Pigs buildings (m3/h per animal ± St. Dev)**	**Overall means of ventilation rate of WCF Pigs buildings (m3/h per anima ± St. Dev l)**	**External Temperature (°C ± St. Dev)**	**External RH (% ± St. Dev)**
May	24.6 ± 2.8	24.0 ± 3.1	72 ± 15	67 ± 15	96.45 ± 25.41	94.35 ± 23.52	19.74 ± 163	70 ± 13
June	28.0 ± 3.2	28.9 ± 3.4	79 ± 14	78 ± 16	107.55 ± 29.76	108.66± 27.86	23.29 ± 1.69	62 ± 13
July	29.44 ± 3.5	28.95 ± 2.8	58 ± 9	62 ± 7	119.85 ± 26.54	118.80 ± 23.43	22.34 ± 1.75	59 ± 13

Table 1. Microclimatic parameters inside and outside the rooms

	Overall lsmeans of ammonia concentration (mg m^{-3})	Overall lsmeans of ammonia emission (mg h^{-1} $animal^{-1}$)	Overall lsmeans of fouled wet surface in the fattening buildings (%)
WCF PIGS	5.31 ±1.01A	579.20 ± 169.33A	37± 7.51 A
WSF PIGS	7.45 ±2.96B	819.36 ± 411.40 B	77.33 ±17.79 B

Table 2. Ammonia concentrations and emissions, percentage of manure on the floor in the WCF (finishing barn housing pigs raised on full concrete floor during the growing phase) and WSF (finishing barn housing pigs raised on slatted floor during the growing phase) facilities.

Values in the same column with superscript ($^{A,\,B}$) differ for $P < 0.001$

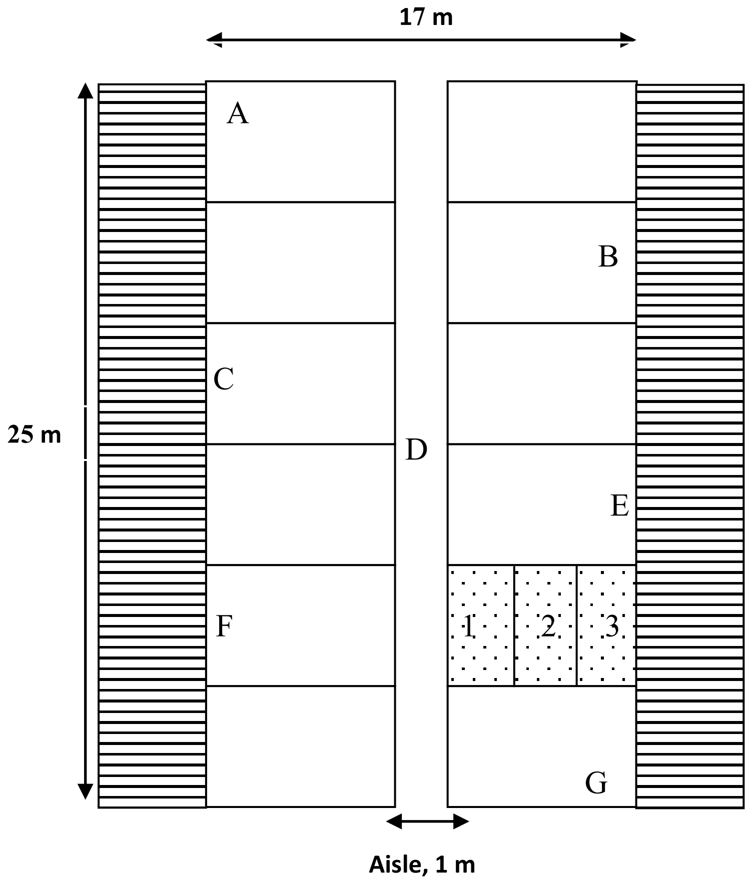

Figure 2. Ammonia concentration sampling points in the finishing facilities (A to G, 1, 2 and 3 are the zones of the pens subdivided for the visual observation of fouling on the floor).

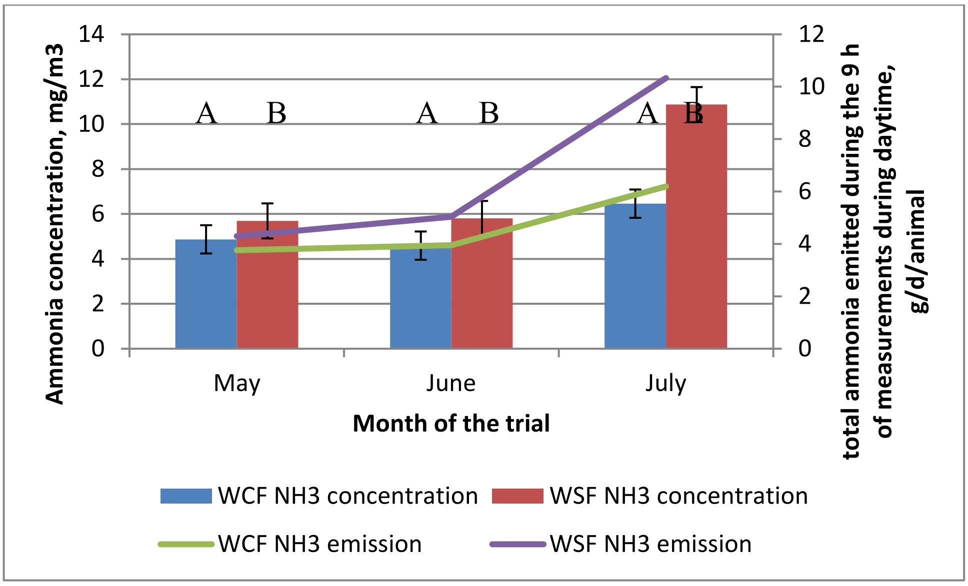

Figure 3. Ammonia concentration and emission in the three months of the finishing phase in the WCF (finishing barn housing pigs raised on full concrete floor during the growing phase) and WSF (finishing barn housing pigs raised on slatted floor during the growing phase) facilities.

Values indicated with (A, B) differ for $P < 0.001$, bars indicate SE

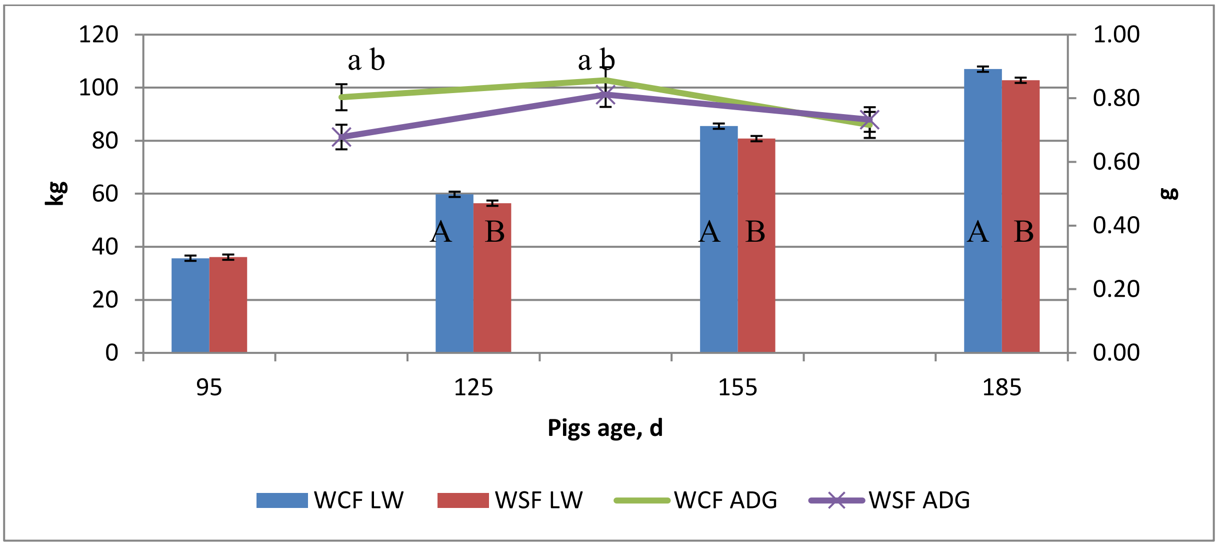

Figure 4. LW and ADG of fatteners in the WCF (finishing barn housing pigs raised on full concrete floor during the growing phase) and WSF (finishing barn housing pigs raised on slatted floor during the growing phase) facilities.

Values indicated with (A, B) differ for $P < 0.001$, values with (a, b) differ for $P < 0.05$, bars indicate SE