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# Relationship between growing pig's housing conditions, behaviours, lesions and health issues under Italian farming system

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**ABSTRACT**

Low space availability, high temperatures and a barren environment may contribute to the occurrence of abnormal behaviours and lesions in intensive pig farming. The present study evaluated the housing conditions (HCs), that influence behavioural measures (BMs), and lesion and health measures (LHMs) in growing pigs reared in an Italian farming system. Data collection was carried out on two groups of pigs in each farm (Farm A and Farm B), tail docked (DT) and tail undocked (UT). The HCs measured were dry and wet bulb temperature, light, humidity, air quality, average body weight, pen level of cleanliness, space, and feeder front allowance. Light intensity was negatively associated with positive behaviour (coefficient: −0.01; $p < 0.001$), while the length of the feeder front was positively associated with the proportion of pigs exploring the pen (coefficient: 65.18; $p = 0.04$). Tail lesion score index (LSI) increased with an increased frequency of negative behaviour (coefficient: 8.05; $p < 0.01$), increased light intensity (coefficient: 0.29; $p < 0.001$) and increased proportion of $CO_2$ (coefficient: 498.31; $p < 0.001$), while it decreased with the average body weight of the pen (coefficient: −4.04; $p < 0.001$) and the space allowance (coefficient: −198.93; $p < 0.001$). Finally, UT pigs showed a greater ($p < 0.001$) tail LSI than DT pigs (126.8 ± 5.71 and 78.5 ± 9.11, respectively for UT and DT pigs). The present study improved the understanding of the effects of HCs, including tail docking, on welfare parameters of growing pigs.

**HIGHLIGHTS**

- Housing and management conditions might play a prominent role on pig health and welfare parameters during growing period.
- Social and exploring attitude behaviours affects both ears and tail lesions.
- Regardless of tail docking, tail injuries were positively associated with negative behaviour, light intensity, and $CO_2$, while they were negatively associated with the average body weight of the pen and the space allowance.

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## Introduction

In modern intensive farming systems, the management practices and the housing conditions used to raise pigs during growing period might lead to a range of different welfare and health problems (Maes et al. 2020). The knowledge and the management of these risks are not only critical for animal welfare, but also for economic sustainability of the pig food chain (Fernandes et al. 2021). Therefore, identification and evaluation of environmental and rearing conditions associated with welfare and health parameters in growing pigs are essential to ensure that these animals are raised in a sustainable manner that minimise the aggressive behaviours (Velarde et al. 2015). Several parameters can affect the welfare and health of growing pigs. These include environmental factors, such as temperature, humidity, and air quality, as well as management practices, such as stocking density, feeding and disease prevention (Godyń et al. 2019). A recent study conducted by Amatucci et al. (2023) showed that warm seasons, which characterise the Mediterranean area, can increase the rate of lesions in all parts of the Italian heavy pig's body. Indeed, higher dry temperatures might increase the stress of pigs and the percentage of aggressive

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behaviours, resulting in increasing injuries percentage in farm, during the transportation and at the abattoir (Schrøder-Petersen and Simonsen 2001; Correa et al. 2014). A major welfare problem in growing pigs is the occurrence of painful and debilitating conditions, including lameness, bursitis, and/or respiratory diseases (Ostanello et al. 2007; Vitali et al. 2021a). These conditions can have a significant impact on the welfare and productivity of pigs and can result in economic losses for farmers (Fernandes et al. 2021). Although there is no 'gold' standard for assessing the health and welfare of swine on finishing farms, some indicators of both health and welfare can be used for this scope. Specifically, tail lesions are regarded as one of the major issues in growing and fattening European pig's (EFSA 2007a). Usually, they arise out by behavioural disorders which are caused or enhanced by stressful conditions. Hence, tail lesions are one of the so called 'iceberg indicators' of welfare in pig farming (Bottacini et al. 2018). Moreover, tail lesions have been linked to additional problems originating from infections of the tail, such as spinal abscesses and pyaemias in different parts of the body, which, in combination with a reduced growth rate, may lead to the carcase condemnation (Harley et al. 2014). It is largely believed that tail docking is an effective tool to minimise tail biting behaviour (Nalon and Briyne 2019). However, several studies have shown the ineffectiveness of this management practice, also demonstrating the high degree of invasiveness and its long-term consequences on pig welfare and health (Sutherland 2015; Valros and Heinonen 2015; Viscardi et al. 2017). Consequently, understanding the main factors associated with unconventional behaviours, lesions and health issues is a key point to improve the pig welfare as well as productivity, particularly regarding the requirements for the Parma Ham PDO (Protected Designation of Origin) production (Bottacini et al. 2018; Vitali et al. 2020, 2021a, 2021b; Amatucci et al. 2023).

Our hypothesis is that housing and management conditions might play a prominent role in pig's welfare and health parameters during growing period. Therefore, the purpose of this study was to assess and enhance the understanding of the relationship between housing conditions, behavioural and health disorders of growing pigs raised under an intensive Italian farming system in tail docked or undocked pigs.

## Material and methods

### Animals, housing, and data collection

The present study involved two farms (Farm A and Farm B) placed in northern Italy. On both farms, animals were raised to produce Parma Ham PDO, therefore, pigs were fed using a restricted list of raw material and must be slaughtered at 160 ± 16 kg (mean ± standard deviation) live body weight and at a minimum age of at least 9 months (Consortium for Parma Ham Protected Designation of Origin 1992). The average body weight ranged from 30 to 60 kg and data collection was carried out from July 2021 until March 2022. Group observations involved a total of 44 different rearing pens (average number of pigs/rearing pen: 31 ± 5.9). In Farm A, data from a total of 15 rearing pens (average number of pigs/rearing pen: 27 ± 7.3) in two observation visits of 10 and 5 pens respectively were collected. The farm was naturally ventilated, and pens had a concrete solid floor and a rectangular area of 25.2 ± 3.99 $m^2$. In Farm B, data from a total of 29 rearing pens (average number of pigs/rearing pen: 33 ± 3.5) during four different observation visits of 6, 8, 8 and 7 pens per visit were collected; the farm was artificially ventilated, and pens had a partially slatted floor and a rectangular area of 34.3 ± 1.63 $m^2$. Pigs from both farms had ad libitum access at water, and the feed was offered as swill type. Pigs with undocked tail (UT) or with docked tail (DT) were reared in separated pens. Lastly, field measurements concerned both housing conditions (HCs) and group animal-based measurements (ABMs) were carried out.

### Measurements and group observations

#### Housing condition measures

The HCs assessed were temperature (dry and wet bulb), humidity, light intensity, proportions of gases in the air such as $CO_2$, $O_2$, $NH_3$ and $H_2S$ and rearing conditions. Rearing conditions consisted in the space allowance available for each pen, the feeder front available for each pig and the level of cleanliness of each experimental pen. According to the method adapted from Vitali et al. (2020), on each day of observation, to assess the HCs between the two farms, trained persons recorded the HCs in each rearing pen. In each stocking pen, dry and wet bulb temperature, humidity, light intensity, and the percentage of gases were recorded at the level of the pigs (about 50 cm high) considering three different spots: the nearest corner to the middle of the room with multiple pens, in the middle, and the opposite corner nearest the outer wall, subsequently the average of the three measures was calculated. Light intensity was measured using a Mini Light Metre (UNI-T UT383, Dongguan City, China). The dry and wet bulb temperature and humidity were recorded using a Datalogger (UNI-T UT330C USB, Dongguan City, China), while the percentage of gases was measured using a portable Dräger X-am® 8000 multi-gas detector (Drägerwerk AG & Co, Lübeck, Germany). Regarding the rearing conditions, the area of the pen was calculated, and the length of the feeder was measured using a Laser Distance Metre (Extech DT40M, Nashua, NH, USA) then divided by the number of pigs to calculate the space allowance and the feeder front available for each animal involved in the experiment. Regarding the level of cleanliness, this parameter was assessed with a score ranging from 0 (dirty) to 1 (clean) adapted from the Welfare Quality® protocol, including an intermediate value of 0.50 points. Finally, each experimental farm furnished as enrichment materials either metal chain or metal chain with wood.

### Animal-based measures

The present experiment recorded two types of ABMs: behavioural ABMs (BMs) and lesion and health ABMs (LHMs). The BMs recorded involved the 'sucking' behaviour defined as sucking any part of another pig's anatomy as though suckling milk (Day et al. 2002), social behaviour, exploratory behaviour, inactive or resting behaviour and other behaviour as defined by the Welfare Quality (2009). The social behaviour consisted either in 'negative' behaviour such as biting or any aggressive social behaviour causing a response from the animal disturbed or 'positive' behaviour such as sniffing, nosing, licking, playing and moving gently away from the other animals without any aggressive or fighting reaction (Welfare Quality 2009). The exploratory behaviour consisted in 'exploring the pen' as sniffing, nosing, licking and 'exploring enrichment material' as playing towards straw or other enrichment material (Welfare Quality 2009). Inactive behaviour was recorded as 'resting' when the animal involved in the observation was showing any social or exploratory behaviour, but it was just laying down, while in other behaviour were recorded any active behaviour not included in the previous categories such as the frequency of animals eating or drinking during the observation (Welfare Quality 2009). Each BM was assessed in the morning, between 10:00 and 11:00 am when the pigs were mostly active, by direct observation of all the pigs in each pen. The observation was carried out five times per pen with two minutes of break between the observations. The frequency of each BM was then expressed as the percentage (%) of the average of the five observations of the animals exhibiting the behaviour over the total of animals in the pen:

$$(n\ of\ pigs\ demonstrating\ the\ behaviour/\ total\ of\ pigs\ in\ the\ pen) * 100$$

During the afternoon of the same observation day, LHMs were assessed. Group observations were performed at distance of 0.5 m from pigs and the number of animals with bursitis and lameness were recorded. Thereafter the percentage of bursitis, and lameness was calculated for each pen (Welfare Quality® 2009). The ear and tail lesions were also evaluated each day of farm assessment according to the recommendations of the Welfare Quality® protocol (2009). Tail lesion scores ranged from 0 (no injuries) to 2 (visible open lesion on the tail, presence of scarring, swelling or partial absence of the tail), including 1(superficial bite along the tail caudectomy but no evidence of swelling) as intermediate value. The same for ear lesions, where the score was: 0 = up to 4 visible lesions; 1 = 5 to 10 visible lesions; 2 = 11 to 15 visible lesions. Subsequently, the result of each pen was expressed as the prevalence of the scores obtained (0, 1, 2). A lesion score index (LSI) was then calculated, which considered both the frequency and the gravity of the lesions (ranging from 0 to 200, where 0 is absence and 200 is all animals with severe lesions):

$$Lesion\ score\ index\ (LSI):\ [\%\ lesion\ type\ 1 + (2 * \%\ lesion\ type\ 2)]$$

Finally, HCs, BMs and LHMs were always assessed by the same evaluator trained on how to apply the Welfare Quality and Classyfarm protocols.

### Statistical analysis

Descriptive, stepwise regression and statistical analyses were carried out using R software (R Core Team 2016). Prior to statistical analyses, descriptive analyses were performed using the jmv package and the function 'descriptives'. The HCs measures, BMs and LHMs are expressed as mean ± standard deviation. A stepwise regression analysis was performed to find the subset of variables in the dataset that results with the lowest error prediction rate following the stepwise selection strategy with backward selection (Gareth et al. 2013, Bruce and Bruce 2017). For the BMs, the variables included in the stepwise regression analysis were the farm, the average pen body weight, and the HCs, while for the LHMs the variables also included the BMs. The stepwise regression analysis was performed using the packages caret, leaps, and MASS. The best predictors coming from the stepwise regression analysis were then fitted in a General Linear Model (GLM) model using the function 'glm'. Values were considered significant at $p \leq 0.05$ and to be a tendency at $0.05 < p < 0.10$.

## Results

Descriptive analysis of HCs measures, BMs and LHMs are reported in Table 1. The space allowance was $0.97 \pm 0.109$ $m^2$/pig. Light intensity was $95.08 \pm 66.001$ lux. The dry temperature of the rearing pen was on average $23.29 \pm 5.251$ °C, while the percentage of humidity and the wet bulb temperature were $70.66 \pm 7.018$% and $19.43 \pm 4.218$, respectively. Lastly, gases detected were on average $20.63 \pm 0.654$ Vol% of $O_2$, $0.26 \pm 0.085$ Vol% of $CO_2$, $8.00 \pm 6.935$ ppm of $NH_3$ and $0.03 \pm 0.128$ ppm of $H_2S$. The frequency of pigs showing resting behaviour was $36.85 \pm 13.889$%. Sucking behaviour represented $0.17 \pm 0.490$% of the pigs. Regarding social behaviour, the percentage of pigs showing positive behaviour was $2.76 \pm 3.126$%, while the percentage of pigs showing negative behaviour was $3.79 \pm 1.645$%. Furthermore, with regard to exploratory behaviour, pigs exploring the enrichment materials were $3.97 \pm 2.724$%, while those exploring the pen were $25.40 \pm 12.592$%. Finally, other behaviour accounted for $27.05 \pm 13.976$% of the pigs involved in the experiment. Regarding LHMs, the rate of bursitis and lameness observed were respectively $0.56 \pm 1.332$% and $1.44 \pm 2.461$%. The percentage of score 0, 1 and 2 of ear lesions were respectively $49.94 \pm 29.245$%, $35.50 \pm 1.641$% and $14.56 \pm 16.940$%. The average ear LSI was $64.62 \pm 42.615$. Score 0, 1 and 2 of tail lesion accounted respectively for the $30.29 \pm 41.395$%, $28.03 \pm 28.649$% and $41.69 \pm 39.320$% of pigs involved in the experiment. Overall, the average tail LSI was $111.40 \pm 75.487$.

**Table 1.** Descriptive analysis of behavioural measures, lesions and health measures and housing condition measures.

| Item[a] | Mean | SD[b] | Min[c] | Max[d] |
|---|---|---|---|---|
| Behavioural measures | | | | |
| Resting, % | 36.85 | 13.889 | 7.33 | 81.08 |
| Sucking behaviour, % | 0.17 | 0.490 | 0.00 | 2.14 |
| Positive behaviour, % | 2.76 | 3.126 | 0.00 | 12.63 |
| Negative behaviour, % | 3.79 | 1.645 | 0.57 | 8.00 |
| Exploring enrichment material, % | 3.97 | 2.724 | 0.00 | 11.00 |
| Exploring the pen, % | 25.40 | 12.592 | 5.56 | 59.33 |
| Other behaviour, % | 27.05 | 13.976 | 6.49 | 60.00 |
| Lesions and health measures | | | | |
| Bursitis, % | 0.56 | 1.332 | 0.00 | 5.26 |
| Lameness, % | 1.44 | 2.461 | 0.00 | 11.11 |
| Ear lesion 0, % | 49.94 | 29.245 | 3.33 | 100.00 |
| Ear lesion 1, % | 35.50 | 21.641 | 0.00 | 73.33 |
| Ear lesion 2, % | 14.56 | 16.940 | 0.00 | 88.24 |
| LSI Ear, n[d] | 64.62 | 42.615 | 0.00 | 176.47 |
| Tail lesion 0, % | 30.29 | 41.395 | 0.00 | 100.00 |
| Tail lesion 1, % | 28.03 | 28.649 | 0.00 | 82.35 |
| Tail lesion 2, % | 41.69 | 39.320 | 0.00 | 100.00 |
| LSI Tail, n[e] | 111.40 | 75.487 | 0.00 | 200.00 |
| Housing conditions | | | | |
| Dry temperature, °C | 23.29 | 5.251 | 16.80 | 33.10 |
| Humidity, % | 70.66 | 7.018 | 59.17 | 81.87 |
| Wet bulb temperature, n | 19.43 | 4.218 | 13.97 | 27.87 |
| Light intensity, Lux | 95.08 | 66.001 | 7.33 | 303.67 |
| $O_2$, Vol% | 20.63 | 0.654 | 18.10 | 20.90 |
| $CO_2$, Vol% | 0.26 | 0.085 | 0.15 | 0.44 |
| $NH_3$, ppm | 8.00 | 6.935 | 0.00 | 30.67 |
| $H_2S$, ppm | 0.03 | 0.128 | 0.00 | 0.77 |
| Space allowance, $m^2$/pig | 0.97 | 0.109 | 0.70 | 1.15 |
| Feeder front, m/pig | 0.37 | 0.071 | 0.20 | 0.45 |

[a]Item: all parameters involved in the descriptive analysis were recorded from each experimental pen ($n = 44$).
[b]SD = Standard deviation.
[c]Min = Minimum value.
[d]Max = Maximum value.
[e]LSI = lesion score index.

### *Effects of housing conditions on behavioural animal-based measures of growing pigs*

The results of the ANOVA analysis on behavioural measures of growing pigs are reported in Table 2. Regarding environmental parameters, increasing dry temperature decreased the proportion of pigs expressing other behaviour (coefficient: −2.22; $p < 0.01$). Wet bulb temperature was positively associated with 'positive' behaviour (coefficient: 0.40; $p < 0.01$) and the proportion of animals exploring the enrichment material (coefficient: 0.36; $p < 0.01$), while light intensity was negatively associated with resting behaviour (coefficient: −0.06; $p = 0.05$). The proportion of gases in the air such as $O_2$ was positively associated with 'positive' behaviour (coefficient: 2.22; $p = 0.03$), while increasing proportion of $CO_2$ decreased the proportion of pigs exploring the pen (coefficient: −103.55; $p < 0.01$). The concentration of $NH_3$ was positively associated with 'positive' behaviour (coefficient: 0.14; $p = 0.04$). Among the rearing conditions, the space allowance was positively associated with 'positive' behaviour (coefficient: 8.62; $p < 0.02$). The feeder front available for each pig was negatively associated with sucking behaviour (coefficient: −2.72; $p < 0.01$) and other behaviour (coefficient: −180.17; $p = 0.04$) and was positively associated with the proportion of pigs exploring the enrichment material (coefficient: 18.40; $p < 0.01$). In addition, increasing the degree of floor cleanness decreased the proportion of pig expressing 'positive' behaviour (coefficient: −2.02; $p = 0.02$), while the average body weight was positively associated with the proportion of animals exploring the pen (coefficient: 0.40; $p = 0.04$). Finally, pigs from Farm A had a lower ($p < 0.01$) frequency of pen exploration ($15.5 \pm 3.95$% and $31.7 \pm 2.48$%, respectively for Farm A and Farm B)

Table 2. Results of the ANOVA analysis on behavioural measures of fattening pigs.

| Variable | Coefficient | SE Coefficient | **LS Mean**[a] | SE Mean | P-value |
|---|---|---|---|---|---|
| Model for resting behaviour, % | | | | | |
| Dry temperature, °C | 0.85 | 0.443 | | | 0.06 |
| $CO_2$, % | 50.60 | 27.182 | | | 0.06 |
| Light intensity, Lux | −0.06 | 0.033 | | | 0.05 |
| Tail docking[b] | | | | | |
| DT | | | 31.1 | 3.74 | 0.07 |
| UT | | | 39.6 | 2.45 | |
| Model for sucking behaviour, % | | | | | |
| Feeder front, m/pig | −2.72 | 0.979 | | | <0.01 |
| Model for positive behaviour, % | | | | | |
| Wet bulb temperature, *n* | 0.40 | 0.135 | | | <0.01 |
| Light intensity, Lux | −0.01 | 0.003 | | | <0.001 |
| $NH_3$, ppm | 0.14 | 0.066 | | | 0.04 |
| $O_2$, Vol% | 2.22 | 1.046 | | | 0.03 |
| Space allowance, $m^2$/pigs | 8.62 | 3.768 | | | 0.02 |
| Floor cleanness, *n* | −2.02 | 0.857 | | | 0.02 |
| Tail docking[b] | | | | | |
| DT | | | 3.6 | 0.50 | 0.06 |
| UT | | | 2.4 | 0.28 | |
| Model for negative behaviour, % | | | | | |
| Farm | | | | | |
| A | | | 2.6 | 0.37 | <0.001 |
| B | | | 4.4 | 0.26 | |
| Model for exploring the enrichment material, % | | | | | |
| Wet bulb temperature, *n* | 0.36 | 0.113 | | | <0.01 |
| Feeder front, m/pig | 18.40 | 6.732 | | | <0.01 |
| Model for exploring the pen, % | | | | | |
| Weight, Kg | 0.40 | 0.198 | | | 0.04 |
| Dry temperature, °C | −3.84 | 2.078 | | | 0.06 |
| $CO_2$, Vol% | −103.55 | 23.951 | | | <0.01 |
| Feeder front, m/pig | 65.18 | 37.980 | | | 0.09 |
| Farm | | | | | |
| A | | | 15.5 | 3.95 | <0.01 |
| B | | | 31.7 | 2.48 | |
| Model for Other behaviour (%) | | | | | |
| Dry temperature, °C | −1.22 | 0.430 | | | <0.01 |
| Feeder front, m/pig | −180.17 | 31.824 | | | <0.001 |

[a]LS Mean = least squared mean.
[b]Tail docking: DT = docked tail; UT = undocked tail.

and a lower frequency ($p < 0.001$) of 'negative' behaviour than Farm B (2.6 ± 0.37% and 4.4 ± 0.26%, respectively for Farm A and Farm B).

## *Effects of housing conditions and behavioural animal-based measures on lesion and health animal based-measures of growing pigs*

The effects of HCs and BMs on growing pigs LHMs are resumed in Table 3. Regarding the health of the pigs, the proportion of bursitis in the pen increased with an increasing proportion of pigs showing sucking behaviour in the pen (coefficient: 1.35; $p < 0.01$), while the proportion of lameness increased with an increasing proportion of animals showing positive behaviour (coefficient: 0.43; $p < 0.001$). The average body weight of the pen had no effect on the health of the pigs involved in the present study. Among the LSIs recorded in the present experiment, the ear LSI increased with an increasing proportion of $CO_2$ (coefficient: 116.79; $p = 0.02$) in the air and with an increasing proportion of pigs exploring the pen (coefficient: 2.44; $p < 0.001$). The LSI of the tail increased with an increasing proportion of pigs showing negative behaviour (coefficient: 8.05; $p < 0.01$), with the increase in light intensity (coefficient: 0.29; $p < 0.001$) and with an increasing proportion of $CO_2$ (coefficient: 498.31; $p < 0.001$), while it decreased the average body weight of the pen (coefficient: −4.04; $p < 0.001$) and the space allowance (coefficient: −198.93; $p < 0.001$). Finally, UT pigs showed a greater tail LSI than DT pigs (126.8 ± 5.71 and 78.5 ± 9.11, respectively for UT and DT pigs; $p < 0.001$).

## Discussion

The present study highlighted the relevance of HCs on the behavioural animal-based measures and on animal behaviour and on lesion and health of growing pigs under a typical Italian rearing system. To the author's knowledge, this is the first study focusing on these aspects in the phase of 30 to 60 kg in Italian pigs as

**Table 3.** Results of the ANOVA analysis on lesions and health measures of fattening pigs.

| Variable | Coefficient | SE Coefficient | LS Mean[a] | SE Mean | P-value |
|---|---|---|---|---|---|
| Model for bursitis, % | | | | | |
| Sucking behaviour, % | 1.35 | 0.364 | | | <0.01 |
| Model for lameness, % | | | | | |
| Positive behaviour, % | 0.43 | 0.099 | | | <0.001 |
| Model for LSI ear, $n$[b] | | | | | |
| Exploring the pen, % | 2.44 | 0.326 | | | <0.001 |
| $CO_2$, Vol% | 116.79 | 48.071 | | | 0.02 |
| Model for LSI tail, $n$[b] | | | | | |
| Negative behaviour, % | 8.05 | 3.005 | | | <0.01 |
| Weight, kg | −4.04 | 0.591 | | | <0.001 |
| Light intensity, Lux | 0.29 | 0.074 | | | <0.001 |
| $CO_2$, Vol% | 498.31 | 54.169 | | | <0.001 |
| Space allowance, $m^2$/pigs | −198.93 | 50.342 | | | <0.001 |
| Tail docking[c] | | | | | |
| DT | | | 78.5 | 9.11 | <0.001 |
| UT | | | 126.8 | 5.71 | |

[a]LS Mean = least squared mean.
[b]LSI = lesion score index.
[c]Tail docking: DT = docked tail; UT = undocked tail.

most of the literature was mainly focused on the finishing period (Bottacini et al. 2018). However, the period between 30 to 60 kg the pigs can still be considered critical for the behavioural and welfare of pig due to the temporal closeness to the transportation, animal mixing, presence of new potential pathogens typical of the new environment and the HCs of the new environment (Guy et al. 2002). In particular, the HCs can play a pivotal role in the growing pig's behaviour and, in turn, affect lesions and health status.

In the present study, some relevant HCs including dry temperature, light intensity and $NH_3$ concentration in the air were observed to affect, independently from the farm, the behaviour, and the LSI of pigs. The increased dry temperature was positively associated with resting behaviour and negatively associated with the explorative pen attitude. In agreement with the present study, Hillmann et al. (2004), observed that as dry temperature increased, growing pigs used moist areas more often and laid more often without contact with pen mates. It is largely known that temperature out of the comfort zone can be a major stressing factor affecting both behaviour and health status of pigs (Urbain et al. 1994; Vitali et al. 2021b). Pigs indeed need to develop a diverse array of behavioural thermoregulation mechanisms in response to elevated temperatures. These include heightened respiration, reduced activity, and changes in resting and lying down behaviours, such as limiting contact with other animals and place body surface in cool, moist places as much as possible (Zervanos and Hadley 1973; Huynh et al. 2005; Shi et al. 2006). The increase in temperature can also lead to a higher frequency of aggressive behaviour as pigs search for wet and isolated areas (Schrøder-Petersen and Simonsen 2001). However, in the present study, the effect of dry temperature on both 'negative' behaviours and LHMs was not evaluated as it was not suggested as predictor by the preliminary stepway regression analysis performed for any of the above-mentioned statistical models.

Among the HCs, the light intensity was also observed to be important for pig behaviour and lesions in the present study. Indeed, our results showed that light intensity was negatively associated with the frequency of resting and 'positive' behaviours and positively associated with the tail LSI, meaning that an increased light intensity could be risk factors for growing pigs. A previous study performed by Martelli et al. (2010) observed that increasing light intensity from 40 to 80 lux reduced the number of hostile interactions which is not in agreement with the present study. However, in agreement with our study, Taylor et al. (2006), observed that pigs tend to prefer darker compartments (2.4 lux) for resting and a preliminary study of Zheng et al. (2015) suggested that light could influence the occurrence of biting events. However, it is important to note that although in the present study the average light intensity recorded was above 95 lux a high variability was observed; indeed, a minimum and maximum values of 7 and 304 lux were found. The high variability could have been affected by the illumination type (artificial or natural). Therefore, our results deserve further clarification and investigation. In fact, as suggested by Götz et al. (2022), further investigation regarding the effect, role and minimum and maximum of light intensity is needed for growing pigs.

In the present study, $NH_3$ concentration was positively correlated with the frequency of 'positive' behaviours. To author's best knowledge, no plausible explanations have been found to this finding, thus, further studies are needed to better evaluate this result. Furthermore, it is widely known that a high $NH_3$ concentration is one of the risk factors affecting mainly the respiratory health of growing pigs (Michiels et al. 2015). Unfortunately, this latter parameter was not proposed as a predictor by the preliminary stepwise regression analysis. It could probably be because the $NH_3$ concentration detected in the present study was always considered optimal (<10 ppm) or acceptable (10 ppm < $NH_3$ concentration < 20 ppm) according to Classyfarm® protocol, except for one experimental pen in Farm B where $NH_3$ was considered as not acceptable (> 20 ppm).

Our results showed that the $CO_2$ proportion was positively associated with resting behaviour, and it was negatively associated with the proportion of pigs exploring the pen. In agreement with our results, a previous study has found that the $CO_2$ concentration was highly correlated with inactivity rates in pigs and could increase the risk of overloading, resulting in the appearance of lesions in the central area of the body and/or the prevalence of bursitis due to prolonged contact of bone prominences with the floor (EFSA 2007b). However, since the resting behaviour was not suggested as predictor for the frequency of bursitis by the stepwise models, we cannot confirm this connection. On the contrary, in the present study it was possible to confirm that the proportion of $CO_2$ was highly associated with both ears and tail lesions. The $CO_2$ is a respiration product; thus, it is mainly associated with the number of animals and with the type of ventilation system and air recirculation (Vitali et al. 2021b). According to the present study, the number of pigs per pen was not related to the proportion of $CO_2$. However, it is plausible to think that higher stocking densities, increased $CO_2$ and by that also 'aggressive' behaviours, as was reported by Vitali et al. (2021b). In this context, the current study revealed that 'negative' behaviours were influenced primarily by the farm, wherein pigs from Farm B exhibited a higher occurrence of these behaviours in comparison to pigs from Farm A. It cannot be excluded that the different ventilation systems between the two farms affected the air quality and the $CO_2$ and $NH_3$ concentrations, however, the health and behaviour of pigs are not only driven by the microclimate and HCs of the farm, but also by management practices. It is widely known that management practices including a low degree of pen cleanness, reduced space and feeder allowance can have negative consequences on the behaviour and health of the growing pigs (Andersen et al. 2020; Ludwiczak et al. 2021). Regarding the cleanness, in the present study, the degree of pen cleanness was negatively associated with positive behaviour and with no other BMs or LHMs. A lower degree of pen cleanness might be the result of non-conventional elimination behaviour in pigs. Indeed, when certain predisposing stressing factors occur, pigs may develop non-conventional behaviour, including the soiling of the pen (Andersen et al. 2020).

In the present study space allowance had no effect on 'negative behaviours' since it was not selected as factor from the stepwise analysis. An effect of space allowance on 'negative' behaviour was expected, as Liorancas et al. (2006) observed that a space allowance of 0.5 $m^2$ for each growing pig expressed more frequently 'negative' behaviours than a space allowance of 1.2 $m^2$. However, in the present study this latter parameter was positively associated with pigs expressing 'positive' behaviours and negatively associated with tail lesions. Furthermore, the current study demonstrated that augmenting the feeder space allocated to each growing pig resulted in a decrease in the incidence of sucking and other behaviours, while simultaneously elevating the occurrence of 'positive' behaviours and pen exploration. This finding aligns with Spoolder et al. (1999), which reported that increasing the feeder space per animal could potentially diminish instances of 'aggressive' behaviours due to feed competition. Likewise, López-Vergé et al. (2018) observed that increasing the feeder space available for each pig during growing period, reduced skin lesions that might be mostly caused by minor appearances of aggressive behaviours. In fact, lesions can be caused by fighting and biting, which can occur on the ears, tail, neck, face, and shoulder (Vitali et al. 2020, 2021a, 2021b; Amatucci et al. 2023). In the present study, our results showed that ear and tail LSI were associated with both HCs and BMs. Indeed, ear LSI were positively associated with the proportion of pigs exploring the pen and $CO_2$. Regarding the effects of pigs exploring the pen on ear LSI, this result remains unclear. However, it might be plausible to think that pen exploration (over-exploring) might be another sign of boredom and poor welfare, as pens are usually located in sterile environments that provide no cognitive stimulation for pigs (Vitali et al. 2021b). Therefore, the biters with no stimuli in the pen might address their attention to the ears of their pen mates. Regarding the effect of $CO_2$ on the increase of ear LSI it could be associated increase in 'aggressive' behaviours, as mentioned before (Vitali et al. 2021b).

For the tail LSI, according to the results obtained in the present study, the caudectomy still remains a significant factor influencing the tail-biting. Indeed, in agreement with previous studies, UT pigs had a higher tail LSI compared with DT pigs (Hunter et al. 2001; Sutherland et al. 2009; Amatucci et al. 2023). Caudectomy practice is still controversial because of the ongoing trauma and pain, which may be caused by the formation of a neuroma, which may indicate an acute sensitivity to discomfort at the amputation site, or the risk of infection. However, tail docking is frequently used as a precautionary procedure against tail biting (EFSA 2007a). Moreover, tail docking is considered one of the major stressing factors during the first days of a piglet's life. In fact, Sutherland et al. (2008) showed an increase in cortisol concentration due to the tail docking. Regardless of the tail docking, a previous study reported that tail biting causes appear to be multi-factorial (EFSA 2007a). Indeed, in the present study it was associated with both HCs factor including the increase in light intensity and the percentage of $CO_2$ and negatively associated with the average pen weight and space allowance and with BHs as it was it was positively associated with 'negative' behaviour. As mentioned earlier in the discussion, these HCs, such as excess $CO_2$ and light and overcrowding, could have favoured aggressive behaviour and stress, leading to an increase in lesions. The close relationship between HCs and BH is therefore clear. Furthermore, as mentioned above, tail lesions are multifactorial, but among the various factors that favour their frequency and intensity, it appears that the increase in $CO_2$ concentration is one of the factors that has caused most of the increase. This is encouraging as it is possible to intervene in the herd to reduce its concentration. Finally, Studnitz et al. (2007) observed that the lack of suitable enrichment materials led to exploratory behaviour towards tails, potentially increasing the likelihood of tail-biting. Both farms provided pigs with not suitable enrichment devices (metal chain and a metal chain with wood; data not shown). In contrast, countries like Sweden rear pigs with intact tails and offer optimal enrichment materials, such as straw. This approach appears to decrease the occurrence of tail lesions, as observed in a study by Wallgren et al. (2016).

## Conclusions

In growing rearing farms in Italy, increases in light intensity and $CO_2$ concentrations can negatively affect growing pig welfare and behaviour, especially in undocked tail pigs, while greater space allowance was shown as an effective tool to mitigate this problem. Moreover, it was also highlighted that both housing conditions and animals' behaviour including social behaviours such as positive or negative together with the explorative attitude of the pen can affect a growing pig's health as well as lesions occurrence and severity. Tail docking confirms to be critically involved in the severity and frequency of tail lesions. Our findings, provide data to increase the evidence useful to pave the way to improve rearing systems to reduce the risks of aggressive behaviour occurrence in pigs, with special attention on the undocked tail pigs. Indeed, respecting the legislation, this management practice should be avoided or strongly reduced. Finally, it is highlighted that is not possible to rear undocked tail pigs in the same rearing conditions where docked tail pigs are successfully reared.

## Disclosure statement

No potential conflict of interest was reported by the authors.

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## Data availability statement

The datasets used and/or analysed during the current study are available from the corresponding author upon reasonable request.

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