



Article

Influence of Increased Light Intensity on the Acceptance of a Solid Lying Area and a Slatted Elimination Area in Fattening Pigs

Svenja Opderbeck ^{1,*}, Barbara Keßler ², William Gordillo ², Hansjörg Schrade ²,
Hans-Peter Piepho ³  and Eva Gallmann ¹ 

¹ Institute of Agricultural Engineering, University of Hohenheim, Garbenstraße 9, 70599 Stuttgart, Germany; eva.gallmann@uni-hohenheim.de

² Bildungs- und Wissenszentrum Boxberg, Seehöfer Str. 50, 97944 Boxberg-Windischbuch, Germany; Barbara.Kessler@lsz.bwl.de (B.K.); William.Gordillo@lsz.bwl.de (W.G.); Hansjoerg.Schrade@lsz.bwl.de (H.S.)

³ Institute of Crop Science, University of Hohenheim, Fruwirthstr. 23, 70599 Stuttgart, Germany; piepho@uni-hohenheim.de

* Correspondence: svenja.opderbeck@uni-hohenheim.de; Tel.: +49-711-459-22506

Received: 14 January 2020; Accepted: 22 February 2020; Published: 27 February 2020



Abstract: Animal welfare labels have been introduced to improve housing conditions in conventional pig systems. Animal welfare should be increased by, e.g. offering a well-accepted and comfortable solid lying area. This study investigates the effect of bright light from an LED spotlight in the slatted area on lying and elimination behavior of fattening pigs. It was tested for two pen designs different in feeder and arrangement of the slatted area with 18 pigs per pen. The study took place in two different compartments (spatial repetition) with two pens of each pen design. The light intensity in the slatted area was increased by two spotlights within one pen of each design as case-control approach. A total of 648 fattening pigs were tested over four and five fattening periods respectively. The lying behavior was assessed by video scan sampling at three different weekdays at three times (morning, noon, evening) on each observation day. On average, the lying area was used by 60–63% of the pigs in the control pens and 67–69% in the spotlight pens. Additionally, a tendential effect of the deviation of the room temperature from the set temperature existed. The fouling of the animals and pen was not affected by the light intensity.

Keywords: lying behavior; pen fouling; fattening pigs; light intensity; solid lying area

1. Introduction

The development of livestock systems has focused primarily on increasing technical and economic efficiency over the last few decades, which has led to intensive livestock housing systems and an associated reduction of animal welfare.

One consequence of this development is that most pigs in conventional systems are kept on fully slatted floors [1]. The requirements for animal welfare in German pig farming have increased during the last few years. One possibility of improving the welfare of conventionally kept pigs could be to offer a solid lying area. Pigs prefer solid surfaces to partial and fully slatted areas for lying [2]. Furthermore, fully slatted floors pose a higher risk for injury to the legs and can cause lameness in pigs [3,4]. The main problem when using solid surfaces is the high risk of fouling of the solid surface, as is known from practical experiences and several studies [5,6]. This increased fouling could lead to poor indoor air quality and increased workload because the surfaces usually have to be cleaned by hand.

If it is possible, pigs separate their elimination area from the lying area [7,8]. The division of functional areas by the pigs and their behavior is influenced by various factors. In addition to the floor design, the temperature, air speed, stocking density, and light intensity influence the choice of the lying or elimination area.

More pigs lie in the slatted area when the temperature is increased [5,9]. Furthermore, the elimination behavior and, consequently, the fouling of the lying area are affected by the temperature. The fouling of the lying area increases with increased ambient temperature [6,10].

Moreover, Larsen et al. [11] showed that pens with high stocking density had a higher risk of fouling.

The air speed in the different areas of the pens also has an influence on the division of the functional areas. Randell et al. [12] showed that the fouling of the solid lying area was much higher when the fresh air first passed into the lying area before entering the elimination area.

Another effect that has the potential to lead the behavior of pigs is the light intensity. Different light intensities were tested in some studies: 5 lx and 100 lx [13] and 2.4 lx, 4 lx, 40 lx and 400 lx [14]. The pigs showed more resting behavior in areas with dimmer light intensities. The results of Taylor et al. [14] showed that the piglets used the areas with high light intensity (40 lx and 400 lx) mainly for elimination.

The division of the functional areas also can be influenced by the design of the pen. Pigs prefer wet, cool areas with low activity for their elimination behavior [12,15]. Therefore, pigs prefer to eliminate near walls or corners and open pen partitions may lead to more elimination because of territorial function [16–18]. The position of the feeder and drinker also influence the pigs' behavior [19,20].

In the present study, the influence of a highly increased light intensity over the slatted area on the elimination and lying behavior of fattening pigs was investigated. This was tested in two different pen designs with a solid lying area during different seasons. The hypothesis was that a higher number of pigs lie in the lying area in pens with a spotlight over the slatted area. Furthermore, lower fouling of the lying area and, consequently, lower fouling of the animals was expected. The focus of the study was on the light intensity factor because it can be integrated easily into existing pig husbandry systems and is low-priced.

2. Materials and Methods

This study was carried out as part of the project “Label-Fit” scheduled for three and a half years from January 2017 to July 2020. The aim of this project was to implement the requirements of the entry-level of the label “The German Animal Welfare Association – For more Animal Welfare” (“*Deutscher Tierschutzbund – Für mehr Tierwohl*”) in the conventional pig holding farming systems in Germany. The main requirements of the entry-level are: 1.1 m² per pig (0.6 m² solid lying area), straw or comparative material for employment, maximum 3:1 animal:feeding place ratio for automatic dry feeder, maximum 8:1 animal:feeding place ratio for mash feeder, maximum 12:1 animal:drinking place ratio, and no tail docking. The focus of this contribution is the design of the solid comfort lying area. For this purpose, four fattening compartments have been rebuilt according to the requirements of the label at the federal pig research and training center “Bildungs- und Wissenszentrum LSZ Boxberg.” The housing and management of the animals were conducted in accordance with German legislation (TierSchNutzVO, 2017) for farm animals. Animals were visually inspected for health issues daily.

The influence of different pen structures (arrangement of the slatted floors and feeder), different floor structures (concrete slatted floor, triangular grid), and increased light intensity were examined in two fattening compartments. This study shows the results of increased light intensity over the slatted area on the use of the functional areas (lying and elimination area) by the pigs.

2.1. Animals

A total of 648 crossbred long-tailed pigs, eighteen pigs per pen and fattening period (50% females and 50% castrated males, German Hybrid × German Piétrain) were used for this study. The pigs were allocated to four pens in each compartment over four (pen design B) and five (pen design A)

fattening periods, respectively (Table 1). The eleven-week-old pigs were fattened over seventeen weeks. The average live weight at the beginning was 30 ± 4.4 kg per pig and 116.8 ± 10.5 kg per pig at the end of the fattening period. The daily weight gain was 963 ± 127 g per pig.

Table 1. Average live weight at the beginning and end of the fattening period and the daily weight gain of the pigs.

Period	Date (day/month/year)	Compartment	Weight at the Beginning (kg per pig)	Weight at the End (kg per pig)	Daily Weight Gain (g per pig)
1	24.01.18 – 22.05.18	C1	31.6 ± 3.7	119.2 ± 5.1	972 ± 100
	03.01.18 – 30.04.18	C2	32.1 ± 4.6	117.8 ± 6.2	943 ± 102
2	30.05.18 – 24.09.18	C1	28.8 ± 5.5	117.7 ± 4.7	969 ± 89
	09.05.18 – 03.09.18	C2	29.9 ± 4.2	118.6 ± 4.1	936 ± 102
3	02.10.18 – 28.01.19	C1	28.1 ± 5.0	117.7 ± 6.4	948 ± 118
	12.09.18 – 07.01.19	C2	29.1 ± 3.0	116.8 ± 5.8	987 ± 106
4	06.02.19 – 03.06.19	C1	32.4 ± 4.6	117.7 ± 4.6	966 ± 91
	16.01.19 – 13.05.19	C2	31.0 ± 3.8	118.6 ± 4.7	974 ± 142
5	12.06.19 – 07.10.19	C1	29.6 ± 4.0	110.0 ± 4.8	874 ± 80
	22.05.19 – 16.09.19	C2	28.1 ± 4.7	111.7 ± 4.7	914 ± 88

2.2. Housing and Experimental Pen Design

There were six pens within each fattening compartment, of which only four were used for this study (Figure 1). The two compartments (C1 and C2) were temperature-controlled forced mechanical ventilated with an air supply from outside through the attic and a porous ceiling. The set temperature decreased from 25°C (day 0) to 22.5°C (day 15) to 19°C (day 60) and stayed at 18°C (day 120) until the end of the fattening period. The minimum ventilation rate was 10% until day 15 and then 25% until the end.

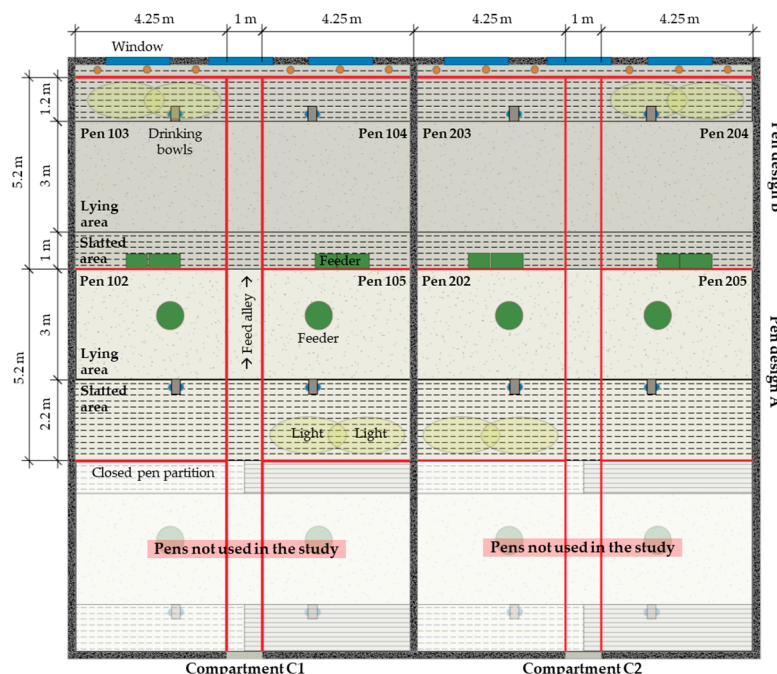


Figure 1. The two compartments with the experimental pen designs A and B.

Two pen designs (pen design A and B), different in the placement of the slatted floors and feeder, were tested. All pens had a size of 4.25×5.2 m, including a lying area of 4.25×3 m (58% of the total pen area, 0.6 m^2 per pig). The slatted floor in pen design A was located on one side (2.2×4.25 m) and the slatted area in pen design B was on both sides ($1/1.2 \times 4.25$ m) of the lying area (42% of the total

pen area, 0.5 m² per pig) (Figure 1). The floor in the lying area was solid concrete with a maximum perforation of 3% and the concrete slatted floor had < 15% perforation with a slat width of 17 mm and 83 mm between the slats. Food and straw were spread over the lying area and the slatted area was wetted before the animals entered the pens. The lying area was cleaned by hand during the first five days in case of fouling. The lying area was cleaned up after the weekly scoring, if necessary, during the entire fattening period to prevent a bad indoor climate.

All pigs were fed ad libitum with a two-phase feeding. In the beginning, the diet contained 13.3 MJ/kg and 170 g/kg crude protein. From a live weight of over 80 kg, the diet contained 10.8 MJ/kg and 145 g/kg crude protein. Animals in pen design A were fed by a round tube mash automat type “Optimat” (Schauer Agrotonic GmbH, Prambachkirchen, Austria) located in the middle of the lying area. The animal:feeding place ratio was 2.25:1. Animals in pen design B were fed by plateau combination feeder (L. Verbakel BV, Sint-Oedenrode, The Netherlands) with an animal:feeding place ratio of 3.6:1. These feeders were located on the partition wall in the smaller slatted area (Figure 1). All pigs had free access to water from two drinking bowls “Suevia 95S” (Suevia Haiges GmbH, Kirchheim/Neckar, Germany), which were located on the slatted floor. The pigs had free access to hay, one wooden beam and two hamper ropes in each pen for environmental enrichment. Approximately 30 g/pig chopped straw was spread automatically on the lying area by the automatic straw distribution system “Spotmix Welfare” (Schauer Agrotonic GmbH, Prambachkirchen, Austria) twice a day (11 a.m. and 3 p.m.).

Four pens of each treatment in two compartments (C1 and C2) were used to investigate the effect of a strong increase of the light intensity over the slatted area on the lying and elimination behavior. A total of eight pens, four of each pen design (Pen design A: 102/105 and 202/205; pen design B: 103/104 and 203/204) were examined (Figure 1).

In each compartment, one pen per pen design remained unchanged and the other received a brighter light intensity over the slatted (designated elimination) area. Two LED spotlights (LED Fluter 30 W, 2400 lm floodlight, cool white) were set up over the slatted area for this purpose (Figure 2). The fattening compartments were illuminated by a total of six fluorescent tubes (warm white light), one above each pen. In addition, there were three windows on the front of each compartment.



Figure 2. Photos of a pen of (a) pen design A and (b) pen of design B with spotlights above the slatted area.

The spotlights and the compartment lighting were switched on from 7 a.m. to 6 p.m. The spotlights were hung 1.4 m above the slatted area. The spotlights were limited by a sheet to ensure that only the slatted area was illuminated (Figure 2). The spotlights were exchanged between the two pens in each compartment after each fattening period to counteract an effect of the location of the pen within the compartments. The average light intensity on pig eye-height for the illuminated area was extremely bright with about 850 lx.

2.3. Data Collection and Aggregation

The temperature and relative humidity inside the compartments was recorded continuously during the fattening periods. The sensors were located 1.5 m above the floor in the feed alley between the two pens of the same pen design.

The first animals were slaughtered from week thirteen, so the number of animals in the stables decreased every week. From the fourteenth week, the number of animals per pen was mostly reduced and, therefore, no longer suitable for data analysis. Consequently, the lying and elimination behavior was recorded during the first thirteen weeks of the fattening period. A video recording device was installed (video cameras, HIKVision DS-2CD2125FWD-1) for 24 h per day during this time. The percentage of lying animals was recorded every 15 min during the first fattening period to determine the activity and respectively, the resting pattern rhythms. Based on this data, three time slots per day with the highest probability of lying pigs were chosen: 5–6 a.m. (morning), 10.30–11.30 a.m. (noon), and 8–9 p.m. (evening). The lying behavior was recorded during these three time slots using scan sampling as an observation method three days a week (Thursday, Wednesday, and Saturday). Usually, 114 observations per period and pen, failures in data due to defects or contamination of the camera were possible.

For recording the lying behavior, screenshots of the first moment in every time slot when all pigs were lying were used. The screenshot of the pen was segmented in twelve parts, i.e., six parts on the lying area and six parts on the slatted area. The number of pigs lying in each part was recorded. Pigs lying on the line were assigned to the part in which more than half of the body or the head was located. Lying was defined as: pigs lying on side or belly with legs stretched out or folded underneath. The percentage of pigs lying on the solid floor was calculated for each pen and time of sampling for the statistical analysis of the lying behavior.

The fouling of the lying surface and of the animals by feces and urine was also recorded directly in the compartments every week to investigate whether the lying area as such is well accepted. Weekly scores were used to monitor the fouling of the pen (usually thirteen observations per fattening period and pen during the first thirteen fattening weeks; failures in data were possible). Consequently, the pen was segmented into twelve parts. The scores for the fouled area were as follows: grade 0 (0–10% fouling), 1 (> 10–25% fouling), 2 (> 25–50% fouling), 3 (> 50–75% fouling), and 4 (> 75–100% fouling). Only fouling caused by feces and urine was considered.

The fouling of the animals was also scored weekly at the same time as the pen fouling from the second to the thirteenth fattening week (usually twelve observations per fattening period and pen; failures in data were possible). Each side of each pig was scored to achieve this: 0 (not fouled), 1 (slightly fouled), 2 (one body part fouled), 3 (two or more body parts fouled), and 4 (completely fouled). An average grade over both sides of the body was then calculated. These average grades were divided into three categories: 0 (not fouled, average grade 0–1), 1 (slightly fouled, average grade 1.5–2.5), and 2 (heavily fouled, average grade 3–4).

The weekly scores were carried out mainly by the same person. One person exclusively executed the evaluation of the lying behavior by video analysis.

Each dataset was aggregated for statistical analysis. The measurements of the lying behavior were summarized over three fattening phases. Fattening phase 1 includes measurements from weeks 1–4, fattening phase 2 from weeks 5–8, and fattening phase 3 from weeks 9–13. Means were calculated for each time of day (morning, noon, and evening) for each fattening phase. Thus, there were nine means for each pen and fattening period used in the data analysis. Only a weekly average score of the fouling of the lying area was used (grade between 0–4) for the analysis of pen fouling. An average value for the fouling of the animals was calculated out of the amounts of the three categories for every week.

Because the compartment temperature might have an important influence on the lying behavior and fouling, a deviation from the set temperature was considered. Consequently, an average compartment and set temperature were calculated for the time before data collection. Averages over the hour before were calculated for the analysis of the influence on the lying behavior. Averages over

the three days before were used for the fouling of the pen and animals. The difference between the compartment and set temperatures resulted in the deviation from the set temperature.

2.4. Experimental Design and Data Analysis

The two compartments and the eight pens represented the spatial and fattening periods temporal repetitions of the experimental treatment in the experimental design. Thus, the measurements in the pens were considered statistically independent. The two pen designs A and B were analyzed separately. The pigs were allocated to the pens randomly but with a consideration of an equal distribution of sex and weight over all the pens. The experiment ran over five fattening periods in pen design A and four periods in pen design B.

The lying behavior was analyzed with a linear mixed model (GLIMMIX procedure, SAS 9.4®). The factors phase (1–3), time of day (morning, noon, evening), and spotlight (with and without) and their interactions were taken as fixed effects. The design effect for the period (pen design A: 1–5, pen design B: 1–4) was also set as a fixed effect. The deviation from the set temperature was used as a covariate because of the expected influence on the lying behavior. In addition, the interactions of the covariate with the spotlight were also tested. The method of Kenward and Roger [21] was used for computing the denominator degrees of freedom for the tests of fixed effects. The random effects for period*compartment and period*compartment*pen were assumed to be serially correlated across levels of phase and time of day, thus, accounting for the repeated measures nature of the data. The anisotropic power covariance structure was assumed for both random effects, allowing for separate autocorrelations for phase and time of day.

The fouling of pen and animals was also analyzed with a linear mixed model (GLIMMIX procedure, SAS 9.4®). In these analyses, the factors of week (1–13) and spotlight (with and without) and their interaction were taken as fixed effects. The fattening period (pen design A: 1–5, pen design B: 1–4) was set as a fixed design effect. The deviation from the set temperature was used as a covariate because of the expected influence on the fouling. In addition, the interactions of the covariate with and without the spotlight were also tested. The method of Kenward and Roger [21] was used for computing the denominator degrees of freedom for the tests of fixed effects. The effect of the week (1–13) was also considered as a random effect for the interactions period*compartment, period*compartment*pen and period*compartment*spotlight. The anisotropic power covariance structure was used to estimate the random effects.

For both models, the approximate normal distribution and homogeneity of variance of the studentized residuals were confirmed graphically using QQ-plots and plots of residuals versus predicted values, respectively, for both models. The data of pen and animal fouling were not normally distributed and were transformed by taking the square root. No fixed or design effects were removed from the models. Comparisons of means were conducted using the Edwards-Berry procedure for controlling the family-wise type I error rate at a level of $\alpha = 5\%$ [22]. Furthermore, estimated effects with adjusted $p < 0.1$ were considered to be suggestive of real effects.

3. Results

The results of the four pens are shown below. Since the building alteration effort after each period would have been too high, a randomized arrangement of the two pens designs inside the compartments was not possible. Therefore, only the treatment “spotlight” with the same pen design were evaluated statistically. The two different pen designs could only be viewed subjectively.

3.1. Temperature and Relative Humidity

The mean compartment temperature and relative humidity for each compartment and period are shown in Table 2. There were no differences between compartment C1 and C2 within a fattening period. However, there were large differences in compartment temperature between the fattening periods due to seasonal effects. Periods 1, 3, and 4 were mainly during winter, while periods 2 and

5 were mainly during summer. There were no differences between the relative humidity related to the period.

Table 2. Average temperature and relative humidity (\pm standard deviation) for each fattening compartment and period (minute data recorded).

Peri-od	Date (day/month/year)	Compartment	Temperature ($^{\circ}$ C)	Relative Humidity (%)
1	24.01.18 – 22.04.18	C1	21.2 \pm 1.8 (min. 16.2; max. 29.1)	46.8 \pm 7.5 (min. 17.; max. 83)
	03.01.18 – 01.04.18	C2	20.3 \pm 1.9 (min. 14.1; max. 28.5)	46.3 \pm 5.1 (min. 30; max. 74)
2	30.05.18 – 26.08.18	C1	27.1 \pm 2.4 (min. 19.8; max. 33.9)	49.1 \pm 6.8 (min. 27; max. 74)
	09.05.18 – 05.08.18	C2	26.3 \pm 2.3 (min. 20.8; max. 33.0)	43.2 \pm 6.8 (min. 21; max. 64)
3	02.10.18 – 30.12.19	C1	20.7 \pm 2.7 (min. 15.5; max. 27.0)	47.6 \pm 6.6 (min. 24; max. 71)
	12.09.18 – 09.12.19	C2	21.5 \pm 2.7 (min. 14.0; max. 28.7)	43.8 \pm 4.4 (min. 30; max. 61)
4	06.02.19 – 05.05.19	C1	21.9 \pm 1.8 (min. 16.4; max. 28.4)	42.8 \pm 6.5 (min. 22; max. 70)
	16.01.19 – 14.04.19	C2	19.9 \pm 1.4 (min. 12.4; max. 25.0)	37.6 \pm 4.3 (min. 24; max. 69)
5	12.06.19 – 08.09.19	C1	26.2 \pm 2.5 (min. 19.1; max. 34.2)	48.5 \pm 7.5 (min. 29; max. 99)
	22.05.19 – 18.08.19	C2	24.8 \pm 2.2 (min. 18.9; max. 32.7)	44.9 \pm 5.0 (min. 28; max. 61)

3.2. Lying Behavior

The summary of the percentage of pigs lying on the solid lying area is shown in Table 3. The average proportion of animals actually lying at different times of day was morning: 99.97%, noon: 96.12%, and evening: 99.80%.

Table 3. Average percentage of pigs (relative to the total number of lying pigs) lying on the solid lying area for each pen design. The n is the number of observations; usually 114 observations per period and pen. SD is the standard deviation.

Pen Design	Treat-ment	Days of Observation	n	Mean (%)	SD (%)	Min. (%)	Max. (%)	Median (%)
A	Control	380	1135	63	17.2	0	100	61
	Spotlight	380	1133	69	17.4	0	100	67
B	Control	304	910	60	15.9	11	100	59
	Spotlight	304	910	67	14.7	17	100	67

A significant effect of the spotlight was found in pen design A. The percentage of animals lying on the solid lying area was 6% higher (1.7 pigs) in pens with increased light intensity compared to the pens without spotlights (63 vs. 69%; s.e. 2.5; $p = 0.0139$). Furthermore, the effect of increased light intensity in pen design B was also significant. The percentage was about 7% higher (1.9 pigs) in pens with spotlights over the slatted area (60 vs. 67%; s.e. 1.6; $p < 0.0001$) (Figure 3).

The fattening phase also had a significant influence on the lying behavior (average s.e. 1.8; $p = 0.0021$) in pen design B. More pigs lay on the lying area during phase 3 compared to phase 1 (phase 3: 68 vs. phase 1: 59%) and phase 2 (phase 3: 68 vs. phase 2: 62%). In addition, the fattening period also had a significant effect on the number of pigs lying in the solid area. During the warmer periods, between one and four fewer pigs (period 1: 58%; period 4: 56%) lay on the lying area than during the colder seasons (period 2: 65%; period 3: 72%).

The deviation from the set temperature had a tendential effect on the lying behavior in pens of design B (average s.e. 2.8; $p = 0.0761$). With increasing deviation, the number of pigs lying on the solid lying area decreased (Figure 4).

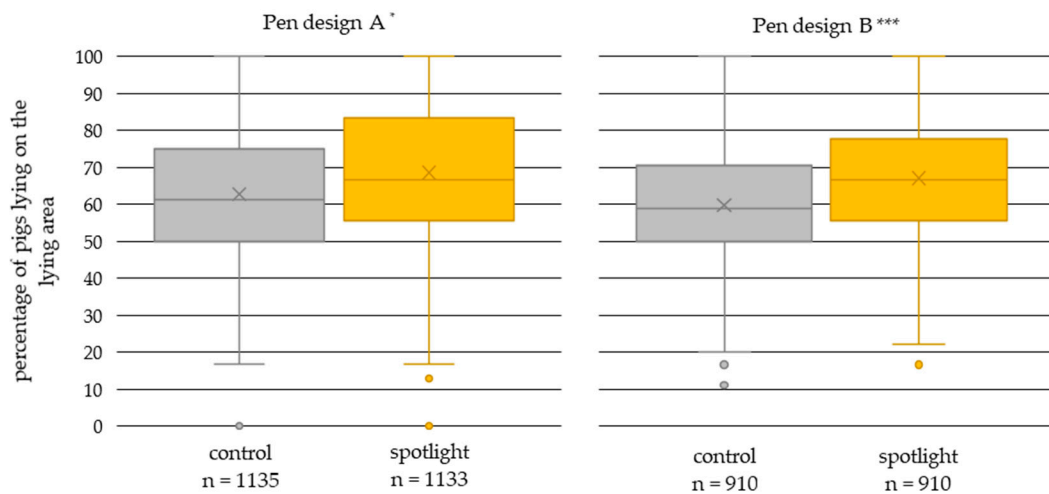


Figure 3. Effect of the spotlight on the percentage of pigs (relative to total number of lying pigs) lying on the solid lying area for pen design A (s.e.2.5; $p = 0.0139$) and B (s.e. 1.6; $p < 0.0001$). Grey boxes represent control pens without spotlights above the slatted area; yellow boxes represent the pens with spotlights above the slatted area. (* = significant effect with $* < 0.05$, $** < 0.01$ $*** < 0.001$; n = number of observations; usually 114 observations per period and pen).

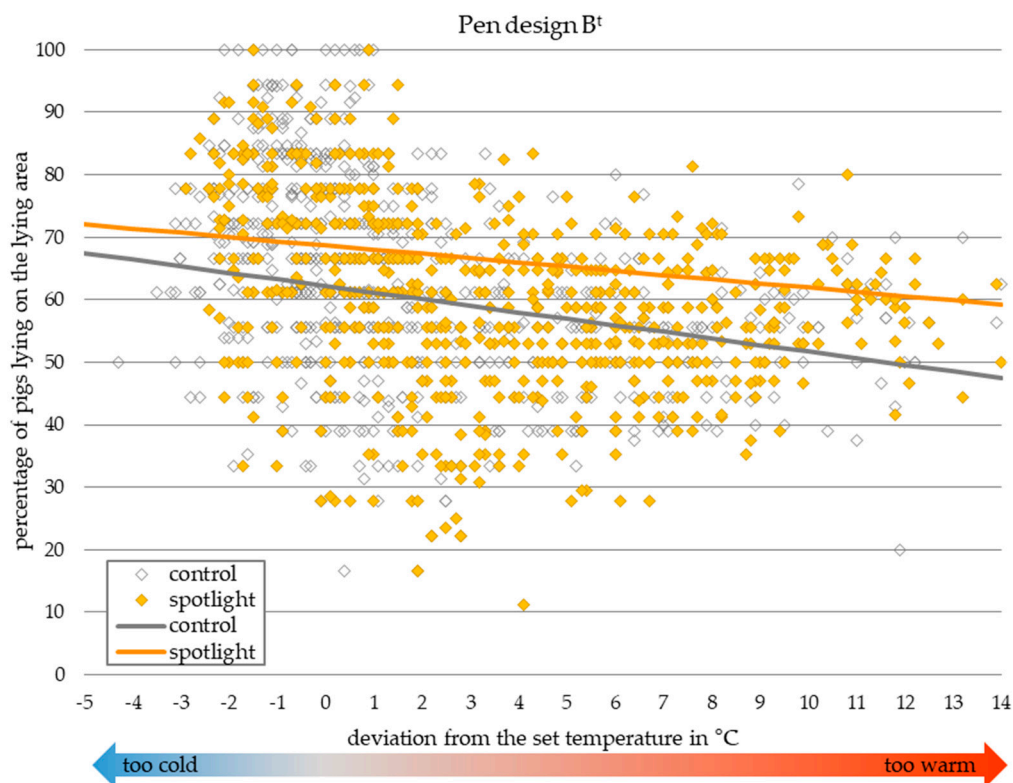


Figure 4. The effect of the deviation from the set temperature on the percentage of pigs (relative to the total number of lying pigs) lying on the solid lying area in pen design B (mean s.e. 3.80; $p = 0.0502$). The diamonds show the raw data. The lines show the trend line. (t = tendential effect).

3.3. Fouling of Lying Area and Animals

The summary for all fouling scorings of the lying area and the animals is shown in Table 4.

Table 4. Effect of the light above the slatted area on the fouling of the lying area and animals. Mean grade of weekly scores for lying area 0 (0–10% fouling), 1 (10–25% fouling), 2 (25–50% fouling), 3 (50–75% fouling), and 4 (75–100% fouling); for animals 0 (not fouled), 1 (slightly fouled), and 2 (heavily fouled). The n is the number of observations, usually thirteen (pen fouling) twelve (animal fouling) observations, respectively per fattening period and pen.

Pen Design	Treatment	Fouling of	n	Mean Score	SD Score	Min. Score	Max. Score	Median Score
A	Control	lying area	124	1.3	0.8	0	3.7	1.2
			117	0.6	0.5	0	1.9	0.5
	Spotlight	lying area	124	1.2	0.8	0	3.7	1.2
			117	0.6	0.5	0	2.0	0.5
B	Control	lying area	102	0.9	0.8	0	3.3	0.7
			96	0.7	0.5	0	2.0	0.6
	Spotlight	lying area	102	1.2	0.8	0	4.0	1.2
			96	0.6	0.5	0	2.0	0.4

No significant effect of the increased light intensity on the fouling of the lying area was found. A significant effect of the fattening week was found for pen design A (mean s.e. 0.08, $p = 0.0023$). The fouling of the lying area at the beginning and the end of the fattening period was less than in the middle. A significant effect of the light on the fouling of the animals was not found.

The fattening week (mean s.e. 0.08; $p = 0.0031$) had an effect in pen design A. The fouling of the animals was higher in the middle and at the end of the fattening period than at the beginning. The deviation from set temperature had a tendential effect on the fouling of animals in both pen designs (A: mean s.e. 0.09; $p = 0.0654$; B: s.e. 0.09; $p = 0.0881$). The higher the temperature and, consequently, the deviation from the set temperature, the higher the fouling of the animals (Figure 5).

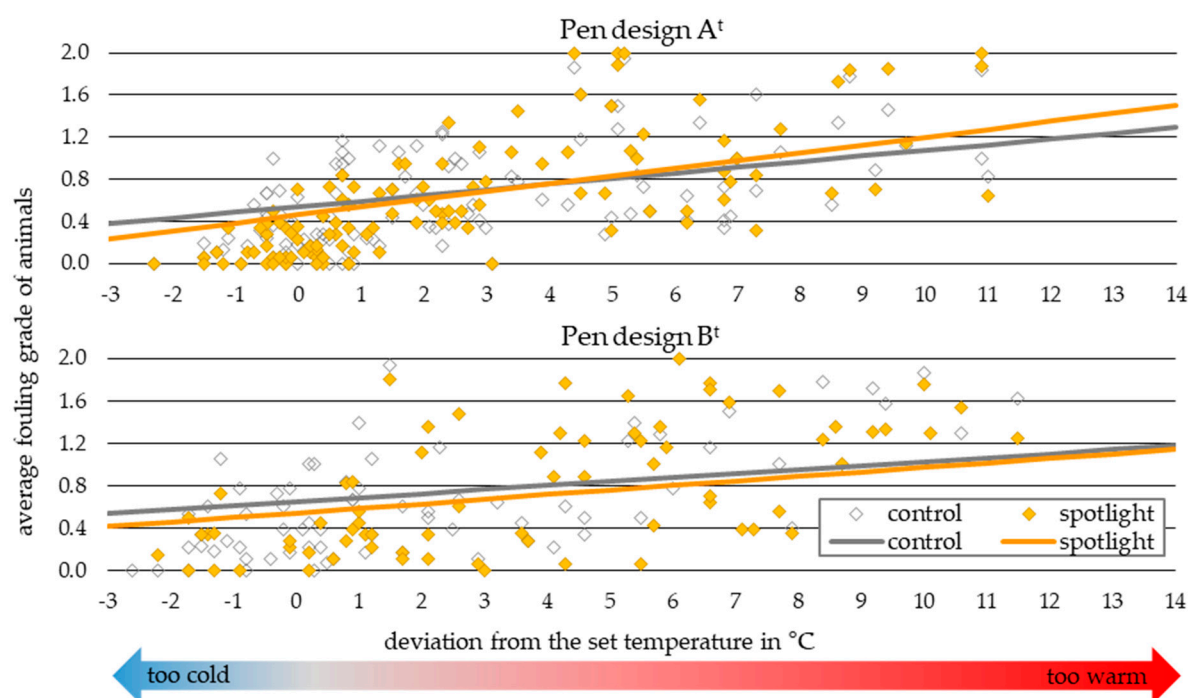


Figure 5. The effect of the deviation from temperature on average fouling of the animals (pen design A: mean s.e. 0.09; $p = 0.0654$; pen design B: mean s.e. 0.09; $p = 0.0881$). The diamonds show the raw data. The lines show the trend line. (t = tendential effect with $p < 0.1$).

4. Discussion

Both pen designs proved to be functional and no adjustments needed to be made. The design of the experiment was sufficient to evaluate the treatment “spotlight” statistically within the two pen designs. The limitation of this study is, that randomization of the pen designs was not possible, and therefore, the data of the two pen designs were only compared descriptively and the differences between the two designs were not evaluated statistically. The defined time slots for the evaluation of the lying behavior of the animals were well chosen with usually more than 97% of pigs lying during the observation.

However, the time period around noon rather reflects the resting behavior and changes very quickly, whereas the animals seem to sleep more and lay over a longer period of time during the mornings and evenings. No differences were found when the data set included only morning and evening observations. A more frequent recording of the lying behavior in future studies, for example, with automatic image/video analysis, could give more detailed and dense information on the pig behavior and short-term changes [23].

On the first day, the pigs were put on their elimination and sleeping areas. Especially on these days, cleaning the lying area can still have a strong influence on the division of the areas. This effect was observed during the study. Subjectively, the cleaning of the pen by hand during the first days led to a positive influence of the division of the functional areas and to a reduction of the fouling of the solid lying area over a longer period of time or even completely. Subjectively, even the weekly cleaning after the scoring sometimes had a positive effect on the fouling. We chose these cleaning intervals because we wanted to make the experiment as practical as possible in order to be able to transfer the results into practice.

Low relative humidity was measured in both compartments over the fattening periods. This low relative humidity could have a positive effect on the animals' behavior because a high relative humidity has the potential to reinforce the effects of the temperature on the pigs [6]. Furthermore, low humidity reduces the urination of the pigs on the solid area [6]. On the other hand, low humidity could result in an increased dust content of the ambient air [24] and, consequently, a higher risk of disease transmission through the dust [24,25]. A high level of fouling can lead to higher ammonia concentrations. The high ammonia concentrations and the low humidity could worsen the indoor climate. This decline of the indoor climate can lead to the impaired welfare of the pigs. Welfare indicators were also collected during the weekly scoring. However, as this study was about improving the acceptance of the lying area, these indicators and the data on the gas measurements have not yet been evaluated.

A significant effect of the increased light intensity on the lying behavior was found for both pen designs. A higher percentage of pigs lay on the solid lying area when there were spotlights over the slatted area. These results led to the conclusion that pigs avoid areas with high light intensity for lying and prefer the dimmer areas. This effect could already be shown in earlier studies by Christison [13] and Taylor et al. [14]. Christison [13] showed that weaning pigs lay slightly more often in low light intensity (5 lx) than in brighter areas (100 lx). The study of Taylor et al. [14] showed that pigs prefer to stay in darker areas (4 lx and less) compared to higher illuminances (40 and 400 lx). Furthermore, the piglets showed more resting behavior in dimmer areas than in brighter.

In this study, no significant effect of the increased light intensity was found for the fouling of the lying area or the animals. However, the fouling of the lying areas in pens with spotlights was slightly lower than in control pens (fouling grades: A: 1.24 to 1.33 and B: 0.86 to 1.2). Taylor et al. [14] showed that increased light intensity led to higher activity and elimination behavior in these areas. Based on the results of this and further studies, it cannot be concluded that the brighter light leads to more elimination behavior in these areas or that these areas are avoided for lying. Another possible reason for the slightly reduced fouling of the lying area could be the pigs' preference for a separate elimination area from the resting or sleeping area [16,17,26]. Therefore, if they avoid brighter areas for resting, they use these brighter areas for defecation to keep the lying area clean.

If the fouling of the animals is seen as a consequence of the fouling of the lying area, then it is obvious that it is not significantly affected by the light, because there were no significant differences in the fouling of the lying area. If the fouling of the animals is considered due to wallowing, then it is effected mainly by other parameters, such as thermoregulation, skincare, health or sexual behavior [27], and the light intensity has no noteworthy influence.

In relation to the results of this and earlier studies, it seems that it could further improve the acceptance if the lying area is dimmed additionally. An extremely large difference between the illuminated and other areas was chosen in this study to find a possible effect. In future studies, the effect of a less increased light intensity should be tested. Taylor et al. [14] showed that a light intensity of 400 lx (about 850 lx in this study) at pig eye-height led to more elimination and less resting behavior.

The temperature is one of the most important factors that influence the behavior of pigs. Under thermoneutral conditions, pigs prefer to rest on a solid floor, and with increased temperatures, the percentage of pigs lying on a slatted area will also increase [5]. In this study, the temperature was examined by using the deviation from the set temperature (average compartment minus set temperature). The lying behavior in pen design B is affected by the deviation from the set temperature. The number of pigs which lay on the solid lying area decreased when temperature and, consequently, the deviation from the set temperature, increased. The effect that more pigs lay on the slatted floor with increasing temperature has been shown in many studies [5,6,9,28]. Spoolder et al. [28] determined that 1.39% more pigs lay on the slatted floor with every degree increase from 16 to 30°C. The critical temperature at which young sows (60 kg) started lying on the slatted floor was 18.8°C in the study of Huynh et al. [6]. The change in lying behavior and the increase in the number of pigs lying on the slatted area could be caused by the lower surface temperature of the slatted floor or by the pigs spreading over the whole pen when the temperature rises. With increased temperature, pigs need more space for lying because they expand their body surface by lying on the side and lay less against other pigs [5,28]. The thermoneutral zone must be observed to prevent these changes in the behavior. The thermoneutral zone of pigs depends on their bodyweight. The thermal tolerance of pigs with a bodyweight of 25–23 kg is 19–21°C, 10–17°C for pigs between 50–70 kg, and 5–17°C for pigs heavier than 85 kg [29]. Aarnink et al. [5] supposed that the influence of the bodyweight on the thermoneutral zone is an indirect effect of the higher heat production. Pigs with a higher bodyweight have larger feed intake and, therefore, they will produce more heat, which results in a higher sensitivity to high temperatures. High temperatures could lead to changes in behavior, especially for fattening pigs with a higher bodyweight.

Nevertheless, in this study, not only the lying behavior was affected by the temperature. The fouling of the animals in all pens was affected by the deviation from the set temperature. The higher the deviation from the set temperature, the higher the fouling of the animals. This higher fouling of the animals can have different causes. It could be a consequence of the higher number of pigs lying in the elimination area because of spreading over the pen; or it could be a consequence of the higher fouling of the lying areas because the pigs lie on the cooler slatted floor or because of wallowing for thermoregulation [5,6,10,27,30,31]. In the study of Aarnink et al. [5], the excretion on the solid floor increased above a certain inflection temperature. The fouling of the solid floor increased from an ambient temperature of 24°C and already above 26°C 50% of the solid floor was fouled by excrement. The excrement on the lying area could explain the higher fouling of the animals with increased temperatures. Even though the fouling of the lying area was not affected significantly by temperature, it increased when the deviation from the set temperature increased. On the other hand, fouling could be a result of wallowing. The most important effect of wallowing is the temperature increase because it is a method of thermoregulation [27].

Another significant effect, which could be explained by the temperature, is the effect of the fattening period on the lying behavior. Fewer pigs lay on the lying area in pen design B during the warmer periods 1 and 4 (mean temperature over 25°C) than during the colder seasons (mean

temperature about 20°C) (period 1: 58%; period 2: 65%; period 3: 72%; period 4: 56%). The temperature in periods 1 and 4 was clearly higher than during periods 2 and 3 (Table 1).

Furthermore, the lying behavior changes depending on the age and body size of the pigs. More pigs lay on the solid area in pen design B during the last fattening phase than during the beginning and middle (beginning: 59%, middle: 62%, end: 68%). The increased body size and the resulting small number of pigs that can lie on the slatted floor could cause this change. Another reason could be that the optimal temperature decreased with increased age and bodyweight. If the optimum is not achieved during the last phase of the fattening, the pigs spread over the pen and need more space of the lying area [5,28,29].

Since randomization of the pen arrangement within the compartments could not be implemented, the differences between two pen designs, A and B, cannot be evaluated statistically. The different arrangements of the slatted floor and feeders were chosen based on findings in previous studies and the practical experiences of the project members. In the current study, the pigs eliminated mainly on the slatted floor near the drinkers and in pen design B next to the feeders on the slatted floor. No differences in pen structure were found in the fouling or lying behavior between the two pen designs. The subjective contemplation suggests that pen design B showed a better performance regarding pen and animal fouling. This could be due either to the arrangements of the slatted floor (both sides of the lying area) or the location of the feeding system (on the edge on the slatted floor). The location of the drinker and feeder could influence the behavior of the pigs in different ways. Aarnink et al. [32] showed that pigs eliminated on the slatted floor where no drinkers or feeders were located, while the pigs in the studies of Vermeer et al. [20] and Simonsen [7] eliminated near the drinkers. In the current study, pigs eliminated on the slatted floor near the drinkers and next to the feeders. As pigs prefer to eliminate near corners and walls [16–18], the slatted floor on both sides of the pen could lead to clean lying areas. Because the feeder was located on the wall, the pigs had the opportunity to eliminate as far as possible away from the feeding area, and they seemed to prefer this [7,32].

5. Conclusion

The results show that strong increased light intensity in the slatted area led moderately to a higher percentage of pigs lying in the lying area. The intensity of the light has no effect on the fouling of the surfaces and animals. Furthermore, the temperature is an important factor which influenced the lying behavior and fouling. Thus, the use of different light intensities can only be one measure among others to increase the acceptance of a lying area. Another possibility that should be investigated is the opposite approach by reducing the light intensity over the lying area to make this area more attractive for lying. In conclusion, a differentiated lighting or darkening strategy in different functional areas seems to be a promising tool for further improvement of the lying and elimination area. A possible strategy for this would be to make the activity and elimination area lighter and the lying area darker. Intelligent lighting control or the targeted use of covers could be used for this strategy.

Author Contributions: Conceptualization, S.O., B.K. and E.G.; methodology, S.O., B.K., W.G. and E.G.; formal analysis, S.O. and H.-P.P.; investigation, S.O., B.K. and W.G.; resources, H.S.; data curation, S.O. and B.K.; writing—original draft preparation, S.O.; writing—review and editing, S.O., H.-P.P., E.G.; visualization, S.O.; supervision, E.G.; project administration, E.G., H.S.; funding acquisition, E.G., H.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Federal Ministry of Food and Agriculture (BMEL) based on a decision of the Parliament of the Federal Republic of Germany via the Federal Office for Agriculture and Food (BLE) under the innovation support program.

Acknowledgments: We thank our project partners Bildungs- und Wissenszentrum LSZ (Boxberg-Windischbuch, Germany), Deutscher Tierschutzbund (Bonn, Germany), Vion Food International (Bad Bramstedt, Germany) and the Friedrich-Loeffler-Institut (Celle, Germany).

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References

1. Bundesministerium für Ernährung und Landwirtschaft (BMEL). *Landwirtschaft verstehen - Fakten und Hintergründe*. 2018. Available online: https://www.bmel.de/DE/Tier/Nutztierhaltung/nutztierhaltung_node.html (accessed on 9 December 2019).
2. Börgermann, B.; Rus, M.; Kaufmann, O. Sensorgestützte Überprüfung des Wahlverhaltens von Mastschweinen - Welche Fußböden und Beschäftigungsangebote werden bevorzugt? *Landtechnik* **2007**, *62*, 228–229. [\[CrossRef\]](#)
3. Candotti, P.; Rota Nodari, S.; Archetti, I.; De Angelis, E.; Caldara, G.; Borghetti, P. Influence of the floor type on the incidence and severity of leg weakness syndrome (LWS) and of articular osteochondrosis (OC) in Italian heavy pig. In Proceedings of the International Society for Animal Hygiene, Saint-Malo, France, 11–13 October 2004; p. 53. Available online: <https://www.isah-soc.org/userfiles/downloads/symposiums/2004/Candotti.pdf> (accessed on 27 February 2020).
4. Gillman, C.E.; Kilbride, A.L.; Ossent, P.; Green, L.E. A cross-sectional study of the prevalence and associated risk factors for bursitis in weaner, grower and finisher pigs from 93 commercial farms in England. *Prev. Vet. Med.* **2008**, *83*, 308–322. [\[CrossRef\]](#) [\[PubMed\]](#)
5. Aarnink, A.J.A.; Schrama, J.W.; Heetkamp, M.J.W.; Stefanowska, J.; Huynh, T.T.T. Temperature and body weight affect fouling of pig pens. *J. Anim. Sci.* **2006**, *84*, 2224–2231. [\[CrossRef\]](#) [\[PubMed\]](#)
6. Huynh, T.T.T.; Aarnink, A.J.A.; Gerrits, W.J.J.; Heetkamp, M.J.H.; Canh, T.T.; Spoolder, H.A.M.; Kemp, B.; Verstegen, M.W.A. Thermal behaviour of growing pigs in response to high temperature and humidity. *Appl. Anim. Behav. Sci.* **2005**, *91*, 1–16. [\[CrossRef\]](#)
7. Simonsen, H.B. Behaviour and distribution of fattening pigs in the multi-activity pen. *Appl. Anim. Behav. Sci.* **1990**, *27*, 311–324. [\[CrossRef\]](#)
8. Watson, T.S. Development of eliminative behaviour in piglets. *Appl. Anim. Behav. Sci.* **1985**, *14*, 365–377. [\[CrossRef\]](#)
9. Feske, I.; Hesse, A.; Hesse, D. Welche Bodenstruktur und Lufttemperatur bevorzugen Mastschweine? *Landtechnik* **2004**, *59*, 46–47. [\[CrossRef\]](#)
10. Savary, P.; Gygas, L.; Wechsler, B.; Hauser, R. Effect of a synthetic plate in the lying area on lying behaviour, degree of fouling and skin lesions at the leg joints of finishing pigs. *Appl. Anim. Behav. Sci.* **2009**, *118*, 20–27. [\[CrossRef\]](#)
11. Larsen, M.L.V.; Bertelsen, M.; Juul Pedersen, L. How do stocking density and straw provision affect fouling in conventionally housed slaughter pigs? *Livest. Sci.* **2017**, *205*, 1–4. [\[CrossRef\]](#)
12. Randall, J.M.; Armsby, A.W.; Sharp, J.R. Cooling gradients across pens in a finishing piggery. *J. Agric. Eng. Res.* **1983**, *28*, 247–259. [\[CrossRef\]](#)
13. Christison, G.I. Dim light does not reduce fighting or wounding of newly mixed pigs at weaning. *Can. J. Anim. Sci.* **1996**, *76*, 141–143. [\[CrossRef\]](#)
14. Taylor, N.; Prescott, N.; Perry, G.; Potter, M.; Le Sueur, C.; Wathes, C. Preference of growing pigs for illuminance. *Appl. Anim. Behav. Sci.* **2006**, *96*, 19–31. [\[CrossRef\]](#)
15. Hacker, R.R.; Ogilvie, J.R.; Morrison, W.D.; Kains, F. Factors affecting excretory behavior of pigs. *J. Anim. Sci.* **1994**, *72*, 1455–1460. [\[CrossRef\]](#) [\[PubMed\]](#)
16. Buchenauer, D.; Luft, C.; Grauvogl, A. Investigations on the eliminative behaviour of piglets. *Appl. Anim. Ethol.* **1982**, *9*, 153–164. [\[CrossRef\]](#)
17. Guo, Y.; Lian, X.; Yan, P. Diurnal rhythms, locations and behavioural sequences associated with eliminative behaviours in fattening pigs. *Appl. Anim. Behav. Sci.* **2015**, *168*, 18–23. [\[CrossRef\]](#)
18. Wechsler, B.; Bachmann, I. A sequential analysis of eliminative behaviour in domestic pigs. *Appl. Anim. Behav. Sci.* **1998**, *56*, 29–36. [\[CrossRef\]](#)
19. Aarnink, A.J.A.; Swierstra, D.; van den Berg, A.J.; Speelman, L. Effect of type of slatted floor and degree of fouling of solid floor on ammonia emission rates from fattening piggeries. *J. Agric. Eng. Res.* **1997**, *66*, 93–102. [\[CrossRef\]](#)
20. Vermeer, H.M.; Altena, H.; Vereijken, P.F.G.; Bracke, M.B.M. Rooting area and drinker affect dunging behaviour of organic pigs. *Appl. Anim. Behav. Sci.* **2015**, *165*, 66–71. [\[CrossRef\]](#)
21. Kenward, M.G.; Roger, J.H. Small sample inference for fixed effects from restricted maximum likelihood. *Biometrics* **1997**, *53*, 983. [\[CrossRef\]](#)

22. Edwards, D.; Berry, J.J. The efficiency of simulation-based multiple comparisons. *Biometrics* **1987**, *43*, 913. [[CrossRef](#)]
23. Nasirahmadi, A.; Hensel, O.; Edwards, S.A.; Sturm, B. A new approach for categorizing pig lying behaviour based on a Delaunay triangulation method. *Animal* **2017**, *11*, 131–139. [[CrossRef](#)] [[PubMed](#)]
24. Honey and McQuilly. Some Physical factors affecting durst cencetration in pig facility. *Can. Agric. Eng.* **1979**, *21*, 9–14.
25. Tan, Z.; Zhang, Y. A review of effects and control methods of particulate matter in animal indoor environments. *J. Air Waste Manag. Assoc.* **2004**, *54*, 845–854. [[CrossRef](#)]
26. Olsen, A.W.; Dybkjær, L.; Simonsen, H.B. Behaviour of growing pigs kept in pens with outdoor runs. *Livest. Prod. Sci.* **2001**, *69*, 265–278. [[CrossRef](#)]
27. Bracke, M.B.M. Review of wallowing in pigs: Description of the behaviour and its motivational basis. *Appl. Anim. Behav. Sci.* **2011**, *132*, 1–13. [[CrossRef](#)]
28. Spoolder, H.A.M.; Aarnink, A.A.J.; Vermeer, H.M.; van Riel, J.; Edwards, S.A. Effect of increasing temperature on space requirements of group housed finishing pigs. *Appl. Anim. Behav. Sci.* **2012**, *138*, 229–239. [[CrossRef](#)]
29. Hillmann, E.; Mayer, C.; Schrader, L. Lying behaviour and adrenocortical response as indicators of the thermal tolerance of pigs of different weights (Abstract). *Anim. Welf.* **2004**, *13*, 329–335.
30. Huynh, T.T.T.; Aarnink, A.J.A.; Spoolder, H.A.M.; Verstegen, M.W.A.; Kemp, B. Effects of floor cooling during high ambient temperatures on the lying behavior and productivity of growing finishing pigs. *Am. Soc. Agric. Eng.* **2004**, *47*, 1773–1782. [[CrossRef](#)]
31. Huynh, T.T.T.; Aarnink, A.J.A.; Truong, C.T.; Kemp, B.; Verstegen, M.W.A. Effects of tropical climate and water cooling methods on growing pigs' responses. *Livest. Sci.* **2006**, *104*, 278–291. [[CrossRef](#)]
32. Aarnink, A.J.A.; van den Berg, A.J.; Keen, A.; Hoeksma, P.; Verstegen, M.W.A. Effect of slatted floor area on ammonia emission and on the excretory and lying behaviour of growing pigs. *J. Agric. Eng. Res.* **1996**, *64*, 299–310. [[CrossRef](#)]



© 2020 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).