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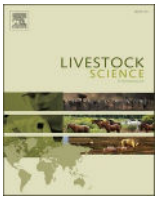

Space density affects resting location and proximity of fattening pigs at night

Mathilde Coutant *, Juliette Michel, Lene J. Pedersen, Mona L.V. Larsen

Department of Animal and Veterinary Sciences, Aarhus University, Tjele, Denmark

HIGHLIGHTS

- The proportion of rest at night did not depend on space allowance.
- Less space per pig increased the probability of lying on the slatted floor.
- Less space per pig increased the probability of lying in full contact with others.
- More space per pig allowed pigs to lie alone on the solid floor.

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ABSTRACT

Night rest is an important component of animal welfare, which may be compromised by high stocking density in fattening pigs. This study investigated how varying space density, achieved by reducing the number of pigs per pen, affect resting location and proximity to other pigs at night throughout the fattening period. A total of 197 pigs across 18 pens were assigned to one of three treatments: 0.7 m^2/pig (0.7 M, 18 pigs per pen), 1.4 m^2/pig (1.4 M, 9 pigs per pen), or 2.1 m^2/pig (2.1 M, 6 pigs per pen), from 30 kg to ~110 kg (11 weeks). On weeks 2, 5, and 10, night video recordings (22:00–07:00) were scanned every 10 min to assess the proportion of pigs resting on different floor types (solid, drained, slatted), and proximity to others (alone, close contact, full contact). All treatments showed a similar overall proportion of pigs lying during the night hours of 95 %. However, 0.7 M pigs had a higher probability of resting on the slatted floor ($P< 0.01$), while 1.4 M and 2.1 M pigs had a higher probability of resting on the solid floor ($P< 0.01$). 0.7 M pigs also showed more full-contact resting compared to 2.1 M ($P< 0.01$), while 1.4 M and 2.1 M pigs rested more often without contact by week 10 ($P< 0.01$). In week 10, 1.4 M pigs rested more on the drained floor and showed more full-contact resting than 2.1 M ($P< 0.01$). These findings suggest that high stocking densities may hinder pigs' possibility to rest on the solid floor and limit their capacity to rest alone, potentially compromising welfare.

1. Introduction

Conventional pig husbandry is generally characterized by high stocking densities, which may affect several aspects of the health and welfare of growing pigs. A high stocking density has for instance been shown to be a risk for tail biting and pen fouling (Coutant et al., 2025a; Larsen et al., 2018ab; Pedersen, 2018). With a high number of pigs in a pen also comes an increased competition to access pen resources, potentially leading to agonistic behaviours and impaired welfare (reviewed by Chidgey, 2023). In contrast, increasing the amount of space available per pig has shown positive effects in reducing or even preventing damaging behaviour (Andersen et al., 2023; Vermeer et al., 2017), improving feed intake and growing patterns (Andersen et al., 2023; Kim et al., 2017), and is thought to promote the expression of positive behaviours including play and explorative behaviour (Chidgey, 2023). While the effect of space density has been investigated on several behavioral patterns, sleep, or general resting at night, is an important aspect of welfare that remains largely understudied. Growing-finishing pigs can spend up to 80 % of their time resting (Ruckebusch, 1972), including approximately 8 h of sleep happening predominantly at night (Campbell and Tobler, 1984). This resting period is highly important for the functioning of metabolism and general welfare. Although it has not been studied specifically in pigs, sleep deprivation in mammals has been linked to major modulations of the metabolism including hormonal

* Corresponding author.
E-mail address: mathilde.coutant@anivet.au.dk (M. Coutant).

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changes, immunosuppression, or increased sensitivity to pain, and can potentially lead to fatal conditions (Villafuerte et al., 2015). Studies in humans also point out the lack of rest as a risk factor for well-being (Shattuck et al., 2019). Rest in general can be described as a prolonged period of inactivity, which requires pigs to lie down in a relaxed and undisturbed manner. However, with <1 m^2 per animal in conventional husbandry, space can quickly become a limiting factor preventing pigs from resting undisturbed (EFSA, 2022). The aim of this study was therefore to investigate how a variation in space density, achieved through a reduction in the number of pigs housed in a pen, impacts night rest throughout the fattening period. In this study, resting was quantified by using lying behavior as a proxy, and the study investigated the resting location (i.e., solid vs. drained vs. slatted floor) and the proximity to other pigs while resting (i.e. lying alone vs. lying in close contact vs. lying in full contact with others) at three space densities.

2. Materials and methods

The current study was carried out in accordance with the Ministry of Food, Agriculture and Fisheries, The Danish Veterinary and Food Administration under act 474 of 15. May 2014 and executive order 2028 of 14. December 2020. A total of 198 pigs across 18 pens were included in the study, performed at the experimental facility of AU-Viborg (Aarhus University, Tjele, Denmark) between September and November 2023. The pigs (DanBred genetics; Landrace x Yorkshire x Duroc) arrived from a local breeder at an average weight of 30 kg and were sent to slaughter at approximately 110 kg, corresponding to 11 experimental weeks. Each pen was divided into three equal-sized areas with either solid, drained (partially slatted), and slatted flooring. The slats were 18 cm wide in the drained area and 8 cm wide in the slatted area, with 2 cm between two slats in both areas. Each pig was assigned one of three treatments: 0.7M: 0.7 m^2 per pig / 18 pigs per pen; 1.4M: 1.4 m^2 per pig / 9 pigs per pen; 2.1M: 2.1 m^2 per pig / 6 pigs per pen. Each treatment was implemented in six pens. All pens had access to the same resources independent of treatment including one feeder with three individual head spaces with ad libitum access to pelleted dry feed, two drinking cups, two fixed wooden beams, a 12 L bucket of straw scattered across the solid floor every day at 11:00, and an automatically controlled sprinkler system (SKOV A/S, Roslev, DK) in place above the slatted floor turned on between 08:00 to 20:00 h. Artificial lights were on from 7:00 to 22:00. The indoor temperature followed a standard curve, beginning at 21 °C upon arrival to 17 °C in week 8 and onwards. One pig from the control treatment was removed from the experimental study prior to data collection (due to health issues). Further details on pen design, management, and caretaking can be found in Coutant et al. (2025b). Video recordings were obtained from 2D cameras fixed above each pen (model DS-2CD2145FWD-I, Hikvision, China). The recordings were observed for 9 h during one night following an undisturbed day (Saturday night, 22:00 to 7:00) at experimental week 2, 5 and 10. Scan sampling was used with a 10 min interval to determine the number of pigs lying with >50 % of the body in different locations of the pen (on solid, drained, and slatted floor) and the number of pigs lying with different levels of proximity i.e., lying alone (>10 cm away from all other pigs), lying with full contact (>50 % of the body in direct contact with at least one other pig) and lying close (all other pigs). All observations were performed by a single observer using the BORIS software (Friard and Gamba, 2016). All statistical analyses were conducted in R version 4.3.2 (R Core Team, 2023) with a 5 % significance level ($P<$ 0.05). Prior to inferential analysis, data were aggregated to one observation per pen per week by taking the sum of pigs in each location and the sum of pigs in each proximity level. Location of rest (area) and proximity during rest were analyzed as beta-binomial responses using the "glmmTMB" package (Brooks et al., 2017). Model assumptions were tested using the 'DHARMa' package (Hartig, 2022), and post-hoc analyses were conducted when relevant using the 'emmeans' package (Lenth, 2024). Both models included treatment (0.7 M, 1.4 M, 2.1 M), week of observation (2, 5, 10), and the interaction between the two as fixed effects. The model for location of rest further included the location (solid, drained, slatted) and its interactions to treatment and week, while the model for proximity further included proximity level (no contact, close contact, full contact) and its interactions to treatment and week as fixed effects. Both models included pen as a random effect.

3. Results

Over the night, pigs were lying in approximately 95 % of observations (scans), with no difference between treatment. For location of rest, the model showed a three-way interaction between treatment, area and week ($P<$ 0.01, Fig. 1). Greater odds of a pig lying on the solid floor were observed in 2.1 M and 1.4 M than in 0.7 M pens, for all weeks. Reversely, higher odds of a pig lying on the drained and slatted floor were recorded in the 0.7 M group than the two space treatments, at the exception of week 10. In week 10, the odds of a pig lying on the drained floor did not significantly differ between the 1.4 M and 0.7 M treatments, but did differ between the two space treatments with lower odds of a pig lying on the drained floor in the 2.1 M treatment. For proximity to other pigs, the model showed a three-way interaction between treatment, week and proximity level ($P<$ 0.01, Fig. 2). Across all weeks, the odds of a pig lying in full contact with other pigs were consistently greater for the 0.7 M than the 2.1 M treatment, and in week 10 also greater for the 1.4 M than the 2.1 M treatment. In contrast, the odds of a pig lying with no contact with other pigs were greater for the 2.1 M than the 0.7 M treatment in weeks 2 and 10, and also greater for the 1.4 M than the 0.7 M treatment in week 10.

4. Discussion

The present study aimed at investigating the effect of space density on resting location and proximity in finishing pigs at night. It is important to acknowledge that lying behaviour was used as a proxy of resting. This behaviour was chosen as it is objectively observable via video observations, but it may not fully correlate with resting or sleeping and should therefore be interpreted with care. Moreover, relying on lying behaviour does not allow detection of potential micro-awakenings or disruptions in sleep architecture, meaning that subtle variations in sleep quality may not have been captured, especially with a scan-sampling approach. The number of pens included in the study was also restricted (6 pens per treatment), which may limit the outcomes of the study. Still, the results indicated clear differences across treatments in the location and proximity of pigs while lying at night. The proportion of lying did not differ across treatments, which may indicate that the amount of rest during the night may not depend on space density, though the quality of rest may vary. This result is not in line with a previous study showing that an increase in space allowance increases lateral and total lying duration in pigs (Nannoni et al., 2019). However, these observations were performed over diurnal hours (7:00 to 19:00) and may therefore not be comparable. While the proportion of pigs resting throughout the night appeared to be the same regardless of the number of pigs in the pen, the location of resting changed. Already at the start of the period, the control pens had a <50 % probability of lying on the solid floor. As the fattening period continued and pigs' weight and size increased, available space on the solid floor was gradually reduced, resulting in the probability of lying in other parts of the pen to increase. In the control pens in the week prior to slaughter, the probability of lying on the solid had decreased to 36 %, with a similar probability of lying on the slatted floor. In contrast, in pens with more space per pig/less pigs, the proportion of pigs lying on the solid floor never dropped below 50 %, with never >15 % pf pigs lying on the slatted floor. In addition, further reducing the number of pigs in a pen from 9 to 6 seemed to increase this positive impact by reducing the probability of lying on the drained floor as well. This result confirms that the solid area is the preferred resting place for pigs, especially when it is supplemented with straw (Larsen

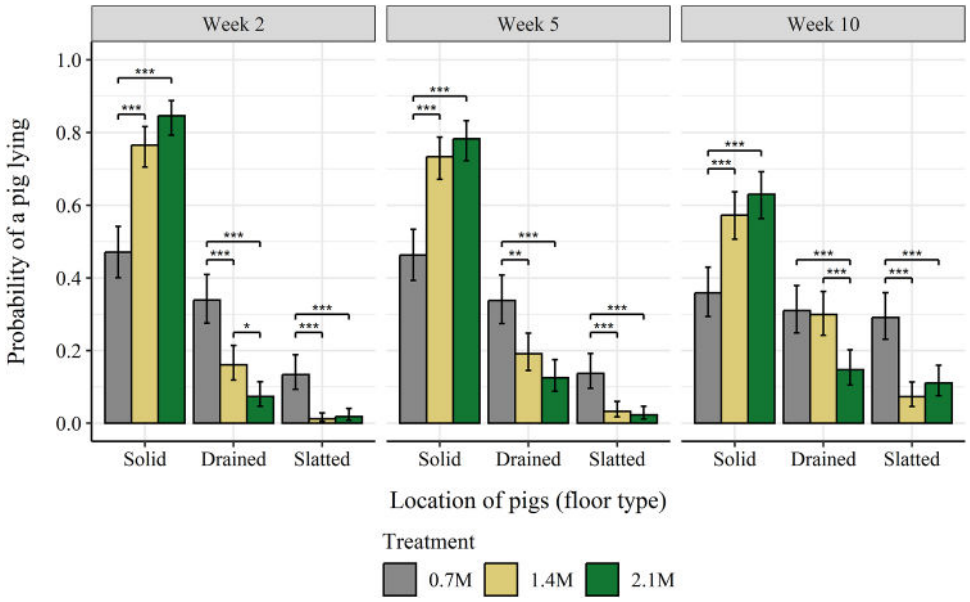

Fig. 1. Probability of a pig lying on the solid, drained or slatted floor for each treatment at week 2, 5 and 10. Model estimates ± 95 % confidence intervals. 0.7M: 18 pigs per pen (0.7 m^2 per pig), 1.4M:9 pigs per pen (1.4 m^2 per pig):, 2.1M: 6 pigs per pen (2.1 m^2 per pig). Post-hoc analysis was conducted to compare treatments within each location for each week, while only the significant pair-wise comparisons are shown. * $P< 0.05$, ** $P< 0.01$, *** $P< 0.001$.

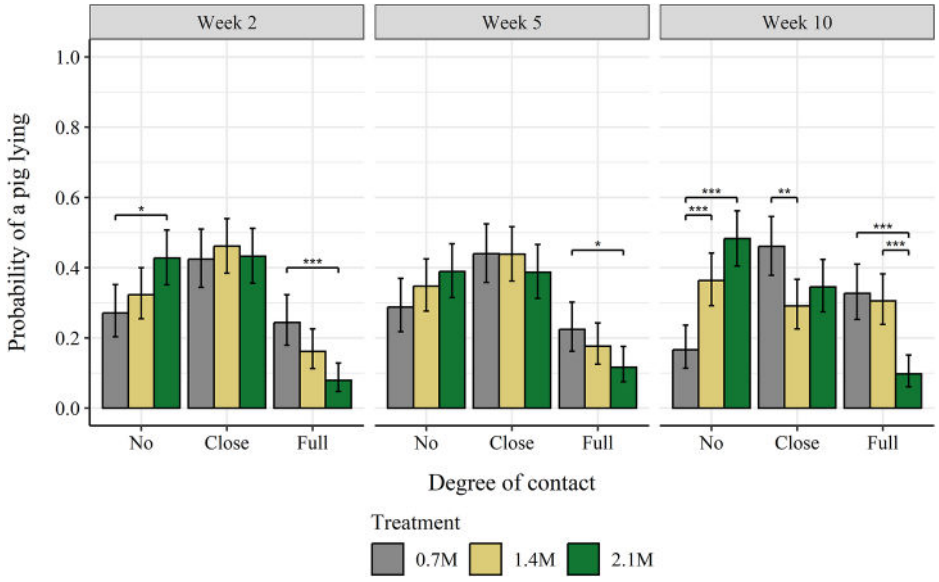

Fig. 2. Probability of a pig lying in no contact with other pigs (No), in close contact (Close), or in full contact (Full) for each treatment at week 2, 5 and 10. Model estimates ± 95 % confidence intervals. 0.7M: 18 pigs per pen (0.7 m^2 per pig), 1.4M: 9 pigs per pen (1.4 m^2 per pig), 2.1M: 6 pigs per pen (2.1 m^2 per pig). Post-hoc analysis was conducted to compare treatments within each proximity level for each week, while only the significant pair-wise comparisons are shown. * $P< 0.05$, ** $P< 0.01$, *** $P< 0.001$.

et al., 2017). Lying outside of the preferred solid resting area, particularly on humid or fouled flooring, may compromise comfort and rest quality, as pigs tend to avoid soiled or wet areas when choosing resting sites (Nannoni et al., 2020; Viklund et al., 2020). It should also be noted that under warmer conditions pigs may choose wetter or slatted areas to cool down (Huynh et al., 2005), but given the relatively cool temperatures during our study (as discussed below), this is unlikely to explain the observed resting patterns. On top of lowering welfare, this loss of functional areas of the pen can further result in pen fouling (Pedersen, 2018), already prevalent in high density pens (Coutant et al., 2025a; Larsen et al., 2018b). The location of rest may also modulate interruptions in rest during the night, although this aspect was not included in the present study.

The proximity to other pigs while resting also differed among treatments. Across all weeks, the pigs consistently had a higher probability of lying with full body contact with other pigs when housed in the control pens as compared to the treatment with the most space per pig, likely because of lacking space. In week 10, the probability of lying in no contact was <20 % in control pens with a contrasting 50 % in the treatment with most space per pig. This forced interaction may, again, disturb the quality of the rest and/or sleep of these pigs, with potential impacts on their welfare. In the treatment with most space per pig and in the early weeks of the fattening period, when the pigs had the most space overall, the probability of lying in full contact was <10 %, and it

remained low throughout the fattening period, which may indicate that pigs had sufficient space to lie apart, regardless of their growing weight. These results indicate that lying in full contact is not preferred if space permits otherwise, under the current conditions provided. The same pattern was observed in the 1.4 M treatment, until the last week of experiment when the prevalence of lying with full contact increased, potentially indicating that the pigs did not have room anymore to lie independently, particularly on the solid floor. Social hierarchy may also contribute to these patterns, as dominant pigs typically occupy preferred resting sites while subordinate animals are more easily displaced to less favorable areas (da Fonseca de Oliveira et al., 2023). In addition, reducing the number of pigs in a pen can alter the stability and expression of the social structure, which in turn may influence how pigs organize themselves when resting, including the extent to which they huddle (Spoolder et al., 1999; Turner et al., 2004). Such social dynamics may therefore interact with space allowance to shape resting behaviour. The level of proximity to other pigs while resting can also be heavily influenced by ambient temperature. In the present study, the thermal environment followed a standard temperature curve, and the experiment was conducted during the fall, a relatively cool season in Denmark, making it unlikely that heat stress was caused by external climatic factors. These findings suggest that pigs prefer to lie apart when space permits, perhaps as part of a local thermoregulation strategy, as pigs are known to adjust proximity and posture in response to thermal conditions (Huynh et al., 2005; Chidgey, 2023). However, this interpretation remains hypothetical, as no direct thermal or physiological measures were collected. This would challenge prior assumptions that physical contact during rest reflects comfort behavior (e.g., Camerlink et al., 2022) and that lateral lying without contact is indicative of heat stress (Chidgey, 2023). Overall, variation in resting proximity appears to reflect a behavioral need to regulate physical contact with other pigs. Our results indicate that the conventional minimum space allowance may restrict this strategy, potentially affecting their welfare. The study showed that although achieving a comparable amount of lying time, pigs housed in high density pens may experience a reduced quality of rest at night as they are forced to rest outside the solid floor and in closer proximity than preferred if space allows it. These results add to existing evidence indicating that present legal space allowances may warrant reconsideration to better support pigs' night-time resting behaviour and general welfare (Chidgey, 2023; EFSA, 2022). Future studies should focus on measuring more direct indicators of the quality of rest and sleep in these conditions, and investigate the correlations between sleep quality, health and welfare.

CRediT authorship contribution statement

Mathilde Coutant: Writing – original draft, Supervision, Methodology, Data curation. **Juliette Michel:** Writing – review & editing, Methodology, Investigation. **Lene J. Pedersen:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition, Conceptualization. **Mona L.V. Larsen:** Writing – review & editing, Visualization, Supervision, Methodology, Investigation, Formal analysis, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Andersen, I.L., Ocepek, M., Thingnes, S.L., Newberry, R.C., 2023. Welfare and performance of finishing pigs on commercial farms: associations with group size, floor space per pig and feed type. Appl. Anim. Behav. Sci. 265, 105979. https://doi.org/10.1016/j.applanim.2023.105979.

Brooks, E.M., Kristensen, K., van Benthem, K.J., Magnusson, A., Berg, C.W., Nielsen, A., Skaug, H.J., Maechler, M., Bolker, B.M, 2017. GlmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. R J. 9, 378–400.

Camerlink, I., Scheck, K., Cadman, T., Rault, J.L., 2022. Lying in spatial proximity and active social behaviours capture different information when analysed at group level in indoor-housed pigs. Appl. Anim. Behav. Sci. 246, 105540. https://doi.org/10.1016/j.applanim.2021.105540.

Coutant, M., Hedemann, M.S., Pedersen, L.J., Larsen, M.L.V. 2025a. Effects of single extensification factors on the risk of tail and ear biting, pen fouling and stomach ulcers in finisher pigs raised in conventional indoor husbandry. *In press.*

Coutant, M., Menard, N., Pedersen, L.J., Larsen, M.L.V., 2025b. Effects of modulating space density via the number of pigs in a pen on feeder use and feeder access in the finishing period. Livest. Sci., 105807

da Fonseca de Oliveira, A.C., Webber, S.H., Ramayo-Caldas, Y., Dalmau, A., Costa, L.B., 2023. Hierarchy establishment in growing finishing pigs: impacts on behavior, growth performance, and physiological parameters. Animals 13 (2), 292. https://doi.org/10.3390/ani13020292.

Campbell, S.S., Tobler, I., 1984. Animal sleep: A review of sleep duration across phylogeny. Neurosci. Biobeha. Rev. 8 (3), 269–300. https://doi.org/10.1016/0149-7634(84)90054-X.

Chidgey, K.L., 2023. Space allowance for growing pigs: animal welfare, performance and on-farm practicality. Animal, 100890. https://doi.org/10.1016/j.animal.2023.100890.

EFSA panel, Nielsen, S.S., Alvarez, J., Bicout, D.J., Calistri, P., Canali, E., 2022. Scientific opinion on the welfare of pigs on farm. EFSA J. 20, 7421.

Friard, O., Gamba, M., 2016. BORIS: a free, versatile open-source event-logging software for video/audio coding and live observations. Methods Ecol. Evol. 7, 1325–1330. https://doi.org/10.1111/2041-210X.12584.

Hartig, F. 2022. _DHARMa: residual diagnostics for hierarchical (Multi-Level /Mixed) regression models_. R package version 0.4.6. Available at: https://CRAN.R-project.org/package=DHARMa [Accessed 10/03/2025].

Huynh, T.T.T., Aarnink, A.J.A., Gerrits, W.J.J., Heetkamp, M.J.H., Canh, T.T., Spoolder, H.A.M., Verstegen, M.W.A., 2005. Thermal behaviour of growing pigs in response to high temperature and humidity. Appl. Anim. Behav. Sci. 91, 1–16. https://doi.org/10.1016/j.applanim.2004.10.020.

Kim, K.H., Kim, K.S., Kim, J.E., Kim, D.W., Seol, K.H., Lee, S.H., Chae, B.J., Kim, Y.H., 2017. The effect of optimal space allowance on growth performance and physiological responses of pigs at different stages of growth. Animal 11 (3), 478–485. https://doi.org/10.1017/S1751731116001841.

Larsen, M.L.V., Andersen, H.M-L., Pedersen, L.J, 2018a. Which is the most preventive measure against tail damage in finisher pigs: tail docking, straw provision or lowered stocking density? Animal 12 (6), 1260–1267. https://doi.org/10.1017/S175173111700249X, 2018.

Larsen, M.L.V., Bertelsen, M., Pedersen, L.J., 2018b. Factors affecting fouling in conventional pens for slaughter pigs. Animal 12 (2), 322–328. https://doi.org/10.1017/S1751731117001586.

Larsen, M.L.V., Bertelsen, M., Pedersen, L.J., 2017. How do stocking density and straw provision affect fouling in conventionally housed slaughter pigs? Livest. Sci. 205, 1–4. https://doi.org/10.1016/j.livsci.2017.09.005.

Lenth, R. 2024. _emmeans: estimated marginal means, aka least-Squares means_. R package version 1.10.3. Avalaible at: https://CRAN.R-project.org/package=emmeans [Accessed 10/10/2024].

Nannoni, E., Martelli, G., Rubini, G., Sardi, L., 2019. Effects of increased space allowance on animal welfare, meat and ham quality of heavy pigs slaughtered at 160Kg. PLoS One 14 (2), e0212417. https://doi.org/10.1371/journal.pone.0212417.

Nannoni, E., Aarnink, A.J., Vermeer, H.M., Reimert, I., Fels, M., Bracke, M.B., 2020. Soiling of pig pens: a review of eliminative behaviour. Animals 10 (11), 2025. https://doi.org/10.3390/ani10112025.

Pedersen, L.J., 2018. Overview of commercial pig production systems and their main welfare challenges. Advances in Pig Welfare. Woodhead Publishing, pp. 3–25.

R Core Team, 2023. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. Available at https://www.R-project.org/ [Accessed 02/09/2024].

Ruckebusch, Y., 1972. The relevance of drowsiness in the circadian cycle of farm animals. Anim. Behav. 20, 637–643. https://doi.org/10.1016/S0003-3472(72)80136-2.

Shattuck, N.L., Matsangas, P., Mysliwiec, V., Creamer, J.L., Matthews, M.D., Schnyer, D., 2019. The role of sleep in human performance and well-being. Human Performance Optimization: The Science and Ethics of Enhancing Human Capabilities. Oxford University Press, pp. 200–233.

Spoolder, H.A.M., Edwards, S.A., Corning, S., 1999. Effects of group size and feeder space allowance on welfare in finishing pigs. Anim. Sci. 69 (3), 481–489. https://doi.org/10.1017/S135772980005133X.

Turner, S.P., Edwards, S.A., 2004. Housing immature domestic pigs in large social groups: implications for social organisation in a hierarchical society. Appl. Anim. Behav. Sci. 87 (3–4), 239–253. https://doi.org/10.1016/j.applanim.2004.01.010.

Vermeer, H.M., Dirx-Kuijken, N.C., Bracke, M.B., 2017. Exploration feeding and higher space allocation improve welfare of growing-finishing pigs. Animals 7 (5), 36. https://doi.org/10.3390/ani7050036.
Viklund, J., 2020. Behaviour and Hygiene of Finishing Pigs Housed in "Moving Floor" and Conventional Pens. Master's thesis. Swedish University of Agricultural Sciences (SLU), Uppsala, Sweden.
Villafuerte, G., Miguel-Puga, A., Murillo Rodríguez, E., Machado, S., Manjarrez, E., Arias-Carrión, O., 2015. Sleep deprivation and oxidative stress in animal models: a systematic review. Oxid. Med. Cell. Longev. 2015, 1–15. https://doi.org/10.1155/2015/234952.