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Creep heating in outdoor farrowing huts may increase piglet welfare without impacting survival and growth

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ABSTRACT

Newborn piglets are prone to hypothermia, and higher mortalities are suggested in outdoor farrowing huts. Therefore, we investigated whether creep heating during the first 7 days after parturition improves piglet survival and welfare. Data (location, behaviour, weight, mortality) were collected from birth to weaning at 7 weeks from 88 litters across seasons. Each hut contained four pens, half with a heated (HEAT) piglet creep area and half of these had a metal bar ('pendulum') to support the sow's lying-down movement. The position of the sow at birth influenced the first piglet entry to the creep (rump facing creep: median 87 min vs snout facing creep: 191 min after the birth of the first piglet; $P = 0.037$). During the first day of life (D0), creep usage was low (2.6 ± 0.65 % of observations) regardless of heating ($P = 0.20$) and season ($P = 0.38$; spring: 1.5 %, summer: 2.7 %, autumn: 1.8 %, winter: 3.1 %). Most piglets on D0 were at the udder (71.5 ± 1.83 %) or in the pen, away from the sow (25.9 ± 1.87 %). Creep usage increased after D0, with more piglets inside if heated (D2, HEAT: 28.0 ± 3.16 % vs not: 6.8 ± 1.85 %; $P < 0.001$), at the expense of being in the pen without sow contact (HEAT: 16.6 ± 2.76 % vs unheated: 32.5 ± 3.06 %; $P < 0.001$). HEAT did not influence piglets in udder contact (e.g. on D2, $P = 0.21$). We found no effect of HEAT on piglet survival ($P = 0.54$) and growth ($P = 0.35$) based on weighing individuals D1, D21, and D49. From D1 to weaning, 16.2 % of liveborn piglets died. The risk of piglet dying tended to higher in piglets being fostered by another sow (in contrast to their biological mother; $P = 0.085$) and higher for males (Hazard ratio vs females: 1.4; $P = 0.004$). Piglet Average Daily Gain (ADG) decreased with increasing litter size at weaning ($P < 0.001$) and was positively associated with the parity of the sow ($P = 0.042$). Season influenced the piglet ADG ($P < 0.001$), being higher during spring (g/day: 321 ± 12^{a}) and autumn ($338 \pm 12\ ^{a}$) than summer (272 ± 11^{b}; winter: 297 ± 14^{ab}). Piglets fostered by another sow had lower ADG (283 ± 13 vs native piglets of the litter: 331 ± 5 g/day; $P < 0.001$). In conclusion, heating resulted in more piglets using of the creep early in life on postnatal day 2, especially in cold weather (mean outdoor temperature effect; $P = 0.030$), indicating a need for more thermal zones inside the hut. These results suggest that additional hut features like heating may increase piglet welfare.

1. Introduction

We aim to explore effects of housing improvements on piglet welfare in free-ranging outdoor conditions, in farrowing huts on paddocks as mandated in Danish organic pig production (Øko-Portalen, 2024). But why is it relevant to study housing improvements for these animals? Arguably, free-ranging organic pigs are expected to experience enhanced welfare compared to those raised indoors in conventional pen systems. Young pigs allowed to stay with their mother in a litter for seven weeks, with unrestricted access to pasture, benefit from social interactions and environmental resources that promote the expression of natural behaviour (McGulloch, 2013; Harvey et al., 2023). However, outdoor conditions may also present thermal challenges that are more pronounced than indoors. For example, fluctuations in climate throughout the day and across seasons may pose risks to the welfare of pigs, particularly during critical periods.

One critical period is during early life, when piglets may face a life-threatening thermal challenge at birth (Berthon et al., 1994). Indeed, high piglet mortality has been reported in the organic production of pigs, whereby sows are housed in huts on paddocks. Across nine outdoor

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organic sow herds in Denmark, the pre-weaning mortality averaged 29.5 %, exceeding the mortality (21.5 %) reported for indoor conventional herds in the same country (Rangstrup-Christensen et al., 2018). We acknowledge that other factors than climate – such as selection of pig breed (Kobek-Kjeldager et al., 2023), management, and the weaning age (circa three weeks later in organic than in conventional indoor pig production; Øko-Portalen, 2024) – may contribute to a higher risk of piglet mortality in outdoor organic herds than in indoor conventional production. Still, animals born in the less insulated huts are expected to experience a broader range of climatic fluctuations in Denmark's four-seasonal temperate coastal climate. In addition, improved thermal comfort and increased piglet survival will support the organic principles of good animal welfare.

Localised heating significantly increased newly born piglets' suckling and survival in indoor pens. The provision of additional heating from birth (34 °C in the floor) is found favourable for re-gaining normal temperature, initiation of suckling, and survival of piglets, tested under well-controlled thermal conditions (around 19–21 °C) in indoor pens (Malmkvist et al., 2006; Pedersen et al., 2007); however, additional heating has not been studied for piglets exposed to the broader climate fluctuations in outdoor herds. Early-life hypothermia in piglets contributes to reduced welfare and may, in combination with low milk intake and unsupported lay-down movements of the sow, also increase the risk of crushing events (Edwards, 2002; Baxter et al., 2013; Pedersen et al., 2013, 2016; Rutherford et al., 2013).

Therefore, we investigated the effect of access to a heated creep area for piglets during the first week after birth across seasons (spring, summer, autumn, and winter) housed in outdoor huts with permanent access to outdoor fields in the temperate coastal climate of Denmark. In addition to creep heating, a pendulum for supporting the sow lying down movement was present in half of the pens in each hut, balanced with the heating treatment. Consequently, pendulum access (yes/no) is included in the statistical analysis and mentioned in the results; the sow's behaviour and use of the pendulum are described in detail elsewhere (Ursu, 2022). In this paper, we focus on whether additional creep heating increases piglet creep use during the early critical period (measured on D0 and D2; D0 denotes the day of birth of the first piglet in the litter). Further, we followed longer-term effects on piglet survival and growth from birth to approximately seven weeks of age, during which the sow and litter were kept together in huts with access to an outdoor paddock. The hypothesis is that creep heating – versus an unheated creep – increases the creep use by piglets and improves survival and growth from birth to weaning. Further, we expect that seasonal effects may influence these responses.

2. Materials and methods

2.1. Animals, housing and management

Sows (type TN70 from Topig Norsvin, topigsnorsvin.com; inseminated with boars of the type Duroc or Landrace x Yorkshire from Danbred, danbred.com) were housed at an organic farm in the Northern part of Jutland, Denmark (DK-9740). The sows were relocated to the farrowing hut in batches of four approximately seven days before the predicted day of farrowing during the study period March 2021 to August 2022, distributed across all seasons: Spring n = 29, Summer n = 31, Autumn n = 16, Winter n = 23. In total, 100 farrowings were allocated, but one sow turned out not to be pregnant. The parity of the farrowing sows was 1–8, with a median of 3 (cf. Table 1). We followed the animals until the separation of piglets from the sow at around seven weeks (actual: 41–57 days) after birth.

The mobile huts (dimensions, L x W x H: 6.6 ×3.3 ×2.2 m, Vanggaard Staldmontage, DK-9700 Denmark) had four individual pens of 4 m^2 for a sow and litter (Fig. 1), each with outdoor access to an individual electrically fenced grass pasture (300 m^2 per sow and litter; 1200 m^2 per hut). Each pen within the hut had barley straw bedding (onset: c. 4 kg

Table 1
Descriptive data on the farrowing sows (n = 88) included in the study, running from March 2021 to August 2022.

Sows	Numbers	Comment		
Allocated	100	Distributed across 25 rounds of four sow pens per hut.		
Excluded	12	Not-pregnant sow (n = 1), electrical/video failure, unverified heating status (n = 5), creep heating turned on too late (n = 6)[1].		
Included in study	88	Creep heating[1] x Pendulum: no I no (n = 24); yes I no (n = 20); no I yes (N = 24); yes I yes (n = 20).		
Description of sows	Mean (SD)	Min-max	Median [25,75 %]	Comment
Parity	3.5 (1.75)	1–8	3 [2, 4]	
Temperament score	10.2 (3.57)	4–20	9 [7, 13]	Scale: 1–21, from sow avoidance to exploratory approach to test person (cf. Table S1).
Body Condition Score	5.2 (1.00)	3–9	5 [5, 6]	At entry. Scale: 1–10, from thin to obese.
Gait score	0.1 (0.24)	0–1	0 [0, 0]	At entry. Scale: 0–2, from sound to severely impaired walking.
Duration of Parturition, min	282 (123.9)	72–642	-	Duration from 1st to last piglet.
SD IBI, min	21.4 (13.13)	5.6–59	-	Variation in Inter-Birth Intervals.
Litter size D1	16.5 (2.44)	12–25	16 [15; 18]	
Functional teats	16.2 (1.06)	13–19	16 [16; 17]	
Litter size D1 after cross-fostering	15.6 (1.77)	11–21	16 [15; 17]	
Litter size D21	13.3 (2.09)	7–18	14 [13; 14]	
Litter size D49	12.8 (2.22)	4–18	13 [12; 14]	
Litter mortality, %	19.0 (12.33)	0–64.3	-	From D0 to weaning at c. D49, including stillborn
Live-born litter mortality, %	16.2 (12.19)	0–69.2	-	From D1 to weaning at c. D49.

[1] included if creep heating was turned on before Birth of First Piglet (BFP) + 1 h (n = 37 was before BFP, n = 3 was 10, 20, and 51 min, respectively, after BFP). Late (excluded): creep heating was turned on 12.9 (3.9) hours after BFP for these litters.

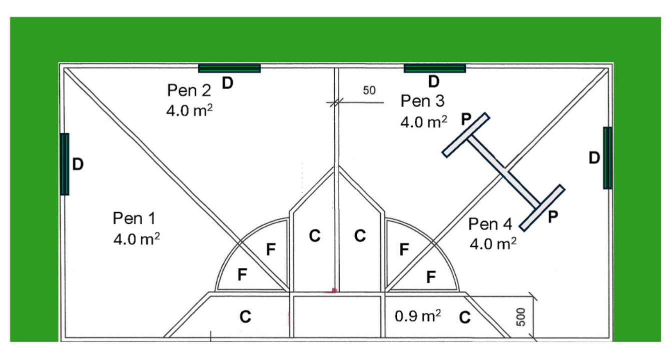

Fig. 1. Diagram of the mobile farrowing hut (L: 6.6 x W: 3.3 x H: 2.2 m) with four pens, each with C: piglet creep area with a standard infrared heat lamp, F: feeder and D: door leading to the outdoor paddock. The inner walls separating the pens had one anti-crushing metal bar and corners with rounded metal bars to protect piglets. Two adjacent pens had a P: pendulum, to support the sow's lying-down movement. Based on drawing from the producer, Vangaard Staldmontage, Denmark.

per m^2, replenished weekly to provide a dry bedding layer) and was equipped with a water drinker, feeding trough, and a covered piglet creep area (0.85 m^2). Daily feeding occurred between hours 9 and 10 in the pen, with commercial dry sow feed close to ad libitum amounts. The sows had free access to drinking water in the pen. Farrowing occurred inside the hut, and the farrowing day is defined as the day of the birth of the first live piglet (D0). D1 is the day after (starting at h 0:00) the farrowing day. Farrowing induction and assistance were not practiced for the sows in our study. Farmer interventions were according to standard practice and included D1: counting, individual weighing, and ID marking of live piglets (one tag per ear, type: a small male back piece with Mini-Sheep FDX-LW chip from Allflex Livestock Intelligence, DK-7620 Denmark). Piglets were shut in the covered creep area for 1–2 h in connection with these and subsequent handling procedures; D3-D4: intramuscular injection with iron supplementation (Uniferon 200 mg/mL, 1 mL per piglet), and males were surgically castrated after procaine injection as local anaesthesia. The farmer recorded interventions (weighing, removal of piglets, reasons for removal, health observations) and medicine used during the study period, along with the date and ID of the piglet and sow.

The farmer performed limited cross-fostering on D1 after all living piglets got a unique ear-tag identification number. In the cases when live piglets outnumbered functional teats of the sow – typically for litter sizes above 16 piglets – the surplus piglets were randomly (i.e., based on a number rather than considering appearance such as size, sex, and vitality) selected for transfer to one or several foster sows. Recipient foster sows in the same hut were used if they had farrowed during the same 24 h as the original sow and had vacant functional teats; otherwise, surplus piglets were moved out of the experiment. After D1, cross-fostering was no longer allowed. Based on the ear-tag identification, the offspring's status was noted as either own or foster piglet. Data from cross-fostered piglets are included in their original litter until D1 and hereafter in the recipient litter.

Sow and piglets had free access to the outdoors; however, they were restricted to a forecourt (0.8×2 m) in front of the door opening of each pen just after parturition. Removal of the forecourt barrier at D9–11 allowed sow and litter access to the full 300 m^2 outdoor enclosure until the end of the study at weaning (separation of sow and piglets) after approximately seven weeks.

2.2. Experimental design and procedure

Our study investigated two main factors, each equally represented in every batch: (1) heating (HEAT) vs no heating in the piglet creep area D0–7, and (2) the presence of a pendulum, aiming to support the lying-down movement of the sow vs. no pendulum in the pen. All combinations of the main factors existed in each hut, i.e., pen 1: unheated piglet creep area, no sow pendulum; pen 2: heated piglet creep area, no sow pendulum; pen 3: unheated piglet creep area, sow pendulum; and pen 4: heated piglet creep area, sow pendulum. The sows were assigned to treatment groups by randomly drawing sow identification numbers from a pool of pregnant and healthy sows at the farm at the onset of each batch. The heat source used in the creep was infrared lighting (bulb 150 W), which was switched on three days before the expected farrowing and turned off after day 7.

Each hut had eight cameras installed, one per pen and one per associated outdoor area. Temperature and relative humidity (RH) could be followed with loggers (RS Pro RS-172K loggers, https://uk.rs-online.com/web/p/data-loggers/1469089) in each pen and piglet creep area. The in-pen sensor was placed on the dividing wall between pens, 1.22 m from the corner opposite the outdoor access and 0.72 m above the ground. The in-creep sensor was placed on the inner part of the dividing wall facing the pen, 0.27 m above the ground of the creep. These sensor data are affected by the location, and density of pigs; therefore, we included climate information (hourly means) from the nearest Danish Meteorological Institute monitoring station (id 6031, Tylstrup, DK-9382, Denmark).

2.3. Data collection

For background information on the sow, as potentially influencing piglet growth and survival, the sow's temperament, gait, and body condition were scored before farrowing (day -7 ± 2). The sow's body condition was additionally scored D21 and D49. The exact dates were noted. As detailed in the following sections, sows and piglets were observed on video recordings of D0 and D2. Further, piglet growth, survival, and necropsy data were sampled from birth to weaning.

Two of the sows (Table 1) died on D9 and D14 for unknown reasons. Subsequently, their offspring (24 live piglets) were moved to foster sows outside the study. The data are included until the day before the sows' deaths. The sows that died had received treatment for fever before dying. Three additional sows were considered febrile on D1-D9 but recovered. Thus, illness occurred in 5.7 % of the studied sows, with no systematic pattern.

2.3.1. Sow temperament: approach-avoidance to human test

We tested sow temperament during the first days after relocation to the experimental hut. The four sows in each batch were tested on the same day, earliest two hours after the morning feeding (i.e., 12:00–14:00) on the outdoor field with a minimum 10-minute break between each sow. The test person wore a light blue disposable overall, different from the clothing of daily caretakers. The test was based on behavioural response to human approaching and proceeded in four steps, as described in Table S1 (Supplementum).

The six scores for each of the 4 test steps (I-IV in Table S1) were summed to one temperament score per sow, with a scale ranging from 1 to 21 (after subtracting 3 to adjust the scale to 1 as the lowest obtainable temperament score). A low temperament score describes sows showing mainly avoidance and fearful responses, whereas a high score describes sows showing approaching and explorative behaviour to the test human.

2.3.2. Sow gait and body condition score (BCS)

The sow's gait before farrowing was scored as 0: no problems during walking, moving around without difficulties; 1: impaired or troubled walking, however, using all four legs. Visible stagger/wobble with the hind part or gait with shortening steps; 2: obviously lame, limited use of at least one leg, moves around with difficulty.

The body condition of the sow was scored using five categories: 1: Very thin (ribs visible; spine, hip, and buttock bones salient and protruding); 2: Thin (ribs covered, but can be felt, spine and hip bone largely visible, buttock bones covered, but obvious and can be felt); 3: Normal (ribs not visible and can hardly be felt; spine hip and buttock bones: Not visible, but can be felt), 4: Little over-conditioned (ribs invisible, cannot be felt, spine and hip bone: can only be felt using firm pressure, Buttock bones: can only be felt using firm pressure. The root of the tail surrounded by fat); 5: Very over-conditioned (ribs covered by a thick layer of fat, the spine cannot be felt. The middle of the body line is seen as a furrow. Hip and buttock bones cannot be felt. The root of the tail is deeply seated, surrounded by fat). Additionally, the sow received a 'minus' or a 'plus', depending on whether the sow was in the lower or upper half of the category. This way, the scaling consisted of ten possible BCSs from very thin to very over-conditioned.

2.3.3. Observations of sow and piglets on video recordings of D0 and D2

Video recordings – saved on a PC from cameras above each pen and outside covering the nearest half of the paddock – were observed (by three trained technical staff) continuously per sow to determine the birth of the first piglet, the duration of parturition (time of the last minus time of the first piglet), interbirth intervals, and the latency for the first piglet of each litter entering the creep. The orientation of the delivering sow relative to the entrance of the piglet creep was noted, with the middle of the creep entrance defined as 0° and the middle of the door to the outside as 180°, opposite to each other in a 360° circular representation of the pen. The body part of the sow lying in the zone between 315° and 45° – i.e., the nearest quarter facing the entrance of the piglet creep area – was noted as either 'snout', 'rump', or 'other body part'. If piglets had not entered the creep area before farmer intervention (e.g., handling, placing them in the creep) or before the set time limit of 24 h from the birth of the first piglet, the time was used as a censored value in the survival analysis for the latency to enter creep.

The position of each piglet was determined by instantaneous scan sampling of video recordings by two trained technical staff every 15 min for 24 h, i.e., on minutes 00–15–30–45 from the birth of the first piglet (D0). On D2, the scan sampling every 15 min was done within fixed two-hour periods distributed across the day: hours 00–02, 04–06, 08–10, 12–14, 16–18, and 20–22. The numbers of piglets in four possible locations were counted: (1) In the piglet creep area (calculated as the total number minus piglets in all other locations), (2) at the udder (touching the sow's udder, defined as the belly region between the front and hind legs of the sow, i.e. a part of the piglet is touching the udder or in contact with another piglet touching the udder), (3) away from the udder (in the pen, not at the udder), and (4) outside the hut. The piglet was assigned to whichever zone (creep area, pen, outside) its head and front legs were in.

The interobserver agreement (proportion of agreement) between the trained observers was considered satisfactory: 98.0 % for sow position at birth (tested for three observers on three sows) and 85.4–99.0 % for piglet locations (i.e., in piglet creep area 97.9 %; at the udder 96.9 %; away 85.4 %; and outside 99.0 %; tested for two observers each scanning 24 h in two litters).

2.3.4. Piglet growth, survival, and necropsy

Live piglets were counted and weighed D1, D21, and D49; the exact date was noted as variation around the days from farrowing did occur. Until D21, dead piglets were collected in bags marked with the finding date and sow identification number for freeze-storage until necropsy. Stored piglets were thawed for 1–2 days and then sexed, weighed, and cut open using the piglet necropsy protocol from Rangstrup-Christensen et al. (2018). From D21 to the end of the study, dead individuals were not stored, but the farmer noted the finding date and identification numbers. If the farmer actively killed pigs, the reason was noted.

We lost track of 21 piglets during the 1.5-year study period (D0-D1: 1 piglet, D2-D21: 7 piglets, D22-D49: 12 piglets, across treatment groups). Status and exit date from the study were recorded for the rest of the piglets (n = 1431) into the categories: Weaned, i.e. alive piglet at the separation from the sow D49 (n = 1098); Moved, i.e. moved out of the study due to cross-fostering D1 (n = 64); Dead, i.e. has been alive and not killed by the farmer (n = 192); Stillborn, i.e. clearly unviable or with a negative lung flotation test in the necropsy (n = 12), Euthanised, i.e. killed based on farmers' evaluation on need for this action (n = 38), Orphan, i.e. moved out of the study due to dead sow (n = 24), and Unidentified, i.e. broken or missing ear tag (n = 3). The number of piglets not making it to weaning at D49, regardless of the reason, was unevenly distributed across sampling periods, with 154 piglets lost during the first two days of life (D0-D1), 145 piglets during the following three weeks until D21, and 34 piglets during the last four weeks until D49. The control group (no creep heating and no Pendulum) had a higher share of the total number of piglets not making it to weaning on D49: 106 piglets (31.8 %), Groups Heat/no Pendulum: 73 piglets (21.9 %); no Heat/Pendulum 86 piglets (25.8 %), and Heat/Pendulum: 70 piglets (21.0 %). Thus, treatments with creep heating had the lowest share of piglets lost from the study until weaning, as indicated by the raw data.

Two of the 88 study sows (Table 1) died on D9 and D14 for unknown reasons. Subsequently, their offspring (24 live piglets) were moved to sows outside the study. The data are included until the day before the sows' deaths. The sows that died had received treatment for fever before dying. Three additional sows were considered febrile on D1-D9 but recovered. Thus, illness occurred in 5.7 % of the studied sows, with no systematic pattern.

Necropsies were performed on dead piglets collected from all the litters allocated to the study at the farm until D21. These data and the sampling record were used to determine whether the piglets were live-born or stillborn. Data on offspring from the experimental litters (n = 88; Table 1) were included in the statistical analysis of live-born mortality as a litter response and the latency of dying for each individual piglet.

2.4. Ethical considerations

The study was conducted according to the legal act on the protection of pigs (Danish Ministry of Environment and Food, 2016) and below the permit-requiring threshold specified in the Danish animal experimentation law (Danish Ministry of Food, Agriculture and Fisheries, 2022). Live-animal sampling was non-invasive. The individual weighing of piglets (three times from birth to weaning) was done by trained farm personnel. The interactions in the approach-avoidance to human test were voluntary (not forced) for the sows.

2.5. Statistical analysis

We analysed most data (Y responses) on piglet location, growth, and litter mortality with a template ANOVA model (1):

$$Y_{ijkl} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \delta_k + (\alpha\delta)_{ik} + (\beta\delta)_{jk} + \gamma_l + \varepsilon_{ijkl}$$

where μ is the general level, α_i is the effect of heating (i = no, yes), β_j is the effect of pendulum (j = no, yes), ($\alpha\beta$) is the interaction between the fixed factors, δ_k is the effect of season (k = spring, summer, autumn, winter), ($\alpha\delta$) and ($\beta\delta$) the interactions between factors and season, γ_l is the effect of sow parity (l = 1–8), and ε_{ijkl} is the residual part. The four seasons, k, were determined by the equinox and solstice. Consequently, spring was March 20 to June 19, summer was June 20 to September 20, autumn was September 21 to December 20, and winter was December 21 to March 19 at the location of the experimental farm. Details on the adaption of the general template model (1) are described for each response variable. The statistical software SAS (version 9.4) was used for calculations, with the Satterthwaite approximation for the denominator degrees of freedom, using the procedure MIXED unless otherwise stated. Random effects were not used unless specified for the analysis of each response variable.

We reduced the models by stepwise removing insignificant terms ($P > 0.10$), starting with the interactions, and removing the term with the highest P-value. Factors with $P \leq 0.10$ and the main fixed factors of the study (α and β) were retained. As the ANOVA test is based on normally distributed data, compliance with dispersion and variance homogeneity was verified by visual inspection of model residual plots at each model reduction step. In some cases, data transformation of response variables was used as described per response variable. The probability level (P) ≤ 0.05 was chosen as the limit of statistical significance, with results between $0.05 < P \leq 0.10$ reported as tendencies. P-values for differences of least square means used for post-tests, i.e., for pairwise comparison in case of a significant effect of a factor with more than two levels. Statistical tests are two-tailed. Means of raw data are reported ± standard error unless otherwise stated.

The template ANOVA model (1) was modified, or other types of statistical analysis were performed, as described for the response variables in the following section.

The latency for the first piglet in the creep was analysed using survival analysis (Klein and Moeschberger, 2003); in 9.5 % of the litters, piglets did not enter the creep before farmer intervention. These events were treated as right censored in the survival analysis based on a Cox regression model (PHREG procedure in SAS), assuming approximately proportional hazard rates between treatment groups based on plots of the survival curves. The analysis included the effects of heating, pendulum, sow parity, and sow position at the birth of the first piglet. Five litters got a latency of 0 because piglets were born directly into the creep; these observations were excluded from a second analysis to investigate the active behaviour of piglets rather than the passive result of their birth site.

The proportion of piglets in different locations ('in the creep', 'at the udder', 'away') was summed for the scans over a day per litter and analysed separately for D0 and D2 using ANOVA model (1) extended to include explanatory variables on the course of farrowing (D0: Duration of parturition from first to last piglet; SD of interbirth intervals) and the number of piglets present (D0: number born; D2: number of piglets D1 minus moved or dead). Arcsine square root transformation of the response variable was used to improve the model fit (approximate normal distribution) in three cases: proportion of piglets in the creep D0, D2, and away D2. The proportion of piglets outside the hut was too low (D0: 0.1 %, D2: 0.3 %) to allow a valid ANOVA. A supplementary analysis explored the relationship between creep use D2 and the outer mean daily temperature (data from the nearest monitoring station of the Danish Meteorological Institute; Tylstrup, DK-9382, Denmark) as a covariate replacing season in the ANOVA model (1).

The total weight of live piglets per litter was analysed separately D1, D21, and D49 using ANOVA model (1) extended to include the scores of sow temperament (values: 4–20), sow gait (scores: 0–1), sow body condition (the pre-farrowing BCS for D1, min-max: 3–9; the BCSs at D21 and D49 respectively, min-max: 3–7), and the litter age (at D21, min-max: 14–27 days; at D49, min-max: 41–57 days) on the weighing day. Some of the 88 litters were distributed over two seasons (D21: n = 17; D49: n = 21); the season used for analysis was set to the most prevalent season until the day of weighing for these litters. Furthermore, birth season was included as an interaction term with the main fixed factors (heat and pendulum) in the statistical analysis.

The Average Daily Gain (ADG) per piglet was calculated as the increase in body weight for the period divided by the actual number of days between weighing and analysed in the same model as for 'The total weight of live piglets'; however, including the litter size, piglet sex (castrated male, intact female) and fostering status (own or foster piglet) and excluding litter age as explanatory variables. Sow within batch identity was used as a random effect to account for piglets within the same litter not being independent observations.

The live-born litter mortality until weaning around D49 was calculated as [(D1 litter size after cross-fostering) minus D49 litter size)/D1 litter size after cross-fostering] and analysed in the same ANOVA model as for 'The total weight of live piglets'; however, including D1 litter size in and excluding litter age.

The latency to death was analysed using survival analysis (Klein and Moeschberger, 2003) on the time of death per piglet, calculated as the observation date of the event minus the date of birth. Piglets that were alive when exiting the study (due to fostering and weaning) were included as right censored (n = 1189). Piglets given the status 'Dead', 'Stillborn' and 'Euthanised, i.e. farmer-killed' were pooled (n = 242). The survival analysis included the effects of heating, pendulum, season, sow parity, sex, cross-fostering status, litter size D1, and sow parity. The calculation was done using the procedure 'Phreg' with the modified sandwich estimator developed for Cox regression ['covs (aggregate)' statement in SAS], with sow identity included as an identifier to account for the relation between piglets in the same litter. The assumption of proportional hazard was met based on the non-crossing and approximate parallel survival curves of the four possible combinations of the two fixed factors (Allison, 2010). A supplementary analysis explored the relationship between the latency for dying and the outer mean daily temperature (Danish Meteorological Institute; Tylstrup, DK-9382, Denmark) as a covariate replacing season in the model.

3. Results

Table 1 describes sows and litters included in the study.

Cross-fostering (D1) occurred for 4.5 % of the piglets. On D1, the farmer removed 65 surplus piglets from 29 study litters and added one or more foster piglets (from litters in the same hut) to 27 study litters. The rest of the surplus piglets were moved to sows outside the study.

The daily 24-hour outdoor temperature averaged (SD) 8.9 (7.40) °C on D2. The mean temperature was −4.0 °C for the coldest and 22.9 °C for the warmest D2 in the data set. According to the in-creep sensors – placed at a wall 0.27 m above the ground – the ambient temperature was ca. 27 % higher in heated creeps [mean (SD): 21.5 (4.29) °C, min-max of means: 8.4–31.2 °C vs not heated: 16.9 (4.45) °C, min-max of means: 2.8–24.2 °C) on D2. The mean pen temperature was equal between groups (D2, mean (SD): HEAT 17.5 (4.19) °C, no heating 17.6 (4.56) °C].

3.1. Latency for the first piglet in the creep

Most sows were positioned with their rump towards the creep (87 %) and fewer sows positioned opposite (snout: 11 %) or crosswise in the pen (1 %) at the time of delivery. The sow position, thus the birth site, influenced the latency for the first piglet in the creep ($\chi^2_1 = 4.4$, $P = 0.037$; median [25 %; 75 % percentile] min, rump: 87 [19; 241] min vs snout: 191 [57; 656] min), with no effect of the fixed factors (HEAT: $\chi^2_1 = 1.1$, $P = 0.30$; Pendulum: $\chi^2_1 = 2.6$, $P = 0.10$). The estimated hazard ratio for the first piglet in the creep was 2.7 (95 % confidence limits: 1.1–6.9) for rump vs snout.

The latency was set to 0 if piglets were born right into the creep (five litters). Excluding these litters from the analysis did not change the overall results (HEAT: $\chi^2_1 = 1.5$, $P = 0.28$; Pendulum: $\chi^2_1 = 2.3$, $P = 0.13$). The birth site influenced how quickly newborn piglets actively reached the creep ($\chi^2_1 = 3.8$, $P = 0.050$; mean durations, rump: 180 min vs snout: 312 min).

3.2. Proportion of piglets in different locations D0 and D2

The proportion of the litter in the creep was low (2.6 ± 0.65 %) during the day of birth (D0), regardless of seasons (Spring: 1.5 %, Summer: 2.7 %, Autum: 1.8 %, Winter: 3.1 %; $F_{3,\ 41} = 0.9$, $P = 0.43$), and the fixed factors (HEAT: $F_{1,\ 51} = 0.7$, $P = 0.41$; Pendulum: $F_{1,\ 51} = 0.4$, $P = 0.52$). During their first day, piglets were mainly at the udder (71.5 ± 1.83 %) or, to a lesser extent, away from the sow in the pen (25.9 ± 1.87 %).

The proportion of the litter in the creep increased markedly from D0 (2.6 ± 0.65 %) to D2 (17.4 ± 2.28 %), with no effects of season (Spring: 24.2 %, Summer: 13.9 %, Autum: 17.5 %, Winter: 15.2 %; $F_{3,\ 45} = 0.6$, $P = 0.65$) or presence of a pendulum for sow support ($F_{1,\ 57} = 0.8$, $P = 0.37$). Creep heating increased the proportion of piglets in the creep D2 (HEAT: 28.0 ± 3.16 % vs no heating: 6.8 ± 1.85 %; $F_{1,\ 57} = 35.2$, $P < 0.001$). The fixed factors (HEAT: $F_{1,\ 57} = 1.6$, $P = 0.21$; Pendulum: $F_{1,\ 57} = 0.0$, $P = 0.88$) and season ($F_{3,\ 51} = 0.7$, $P = 0.54$) did not affect the proportion of piglets at the udder D2 (57.7 ± 2.05 %). However, creep heating halved the occurrence of piglets out in the pen, away from the sow (HEAT: 16.6 ± 2.76 % vs no heating: 32.5 ± 3.06 %; $F_{1,\ 57} = 18.3$, $P < 0.001$; Pendulum: $F_{1,\ 57} = 1.1$, $P = 0.31$). Thus, creep heating changed the piglets' location, drawing them into the creep instead of being dispersed in the pen, keeping their occurrence at the sow udder unaffected (Fig. 2).

A supplemental analysis on D2 creep use was done with outdoor temperature (24 h mean: from −4.0–22.9 °C) replacing season in the model. This analysis revealed an interaction between creep heating and the mean outdoor temperature ($F_{1,\ 51} = 4.7$, $P = 0.036$). The usage of a heated creep appeared higher during cold than during warm weather, whereas the usage of an unheated creep was at a lower level and unaffected by the outdoor temperatures (Fig. 3).

Piglets were rarely seen outdoors in the scanning observations (proportion < 0.3 % of the litter) from birth until two days after; only a few piglets from three litters D0 and six litters D2 visited outside, with no clear seasonal pattern. Detailed results on the studied pigs' use of the

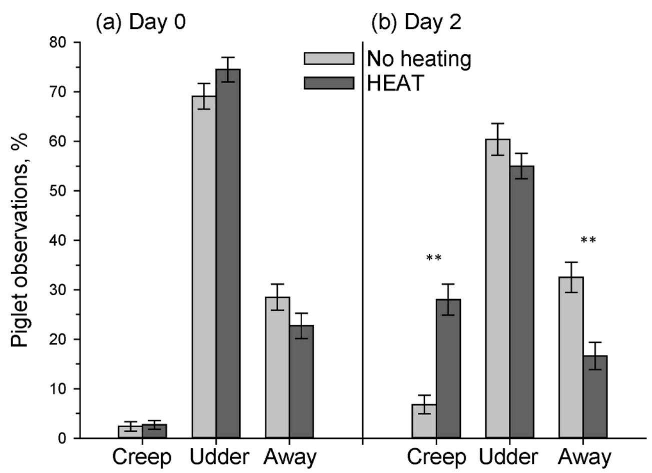

Fig. 2. Scanning of piglet locations presented as the proportion in the creep, at the udder, and away from the sow in the pen during (a) Day 0 and (b) Day 2 after the birth of the first piglet. ** P < 0.001 effect of HEAT.

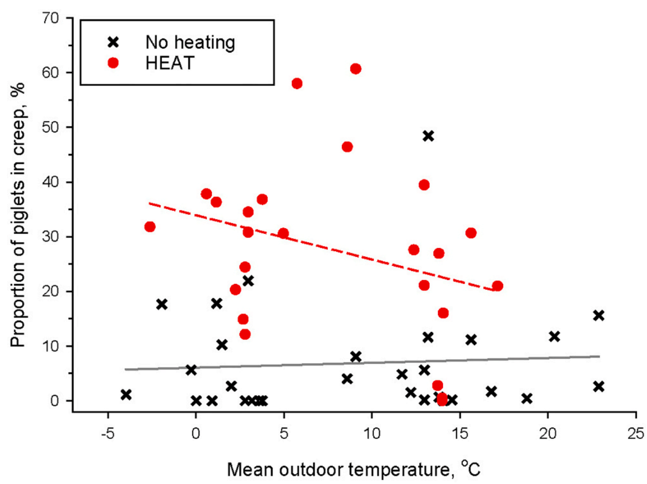

Fig. 3. The proportion of piglets in the creep D2 vs the mean outdoor temperature, with raw data and regression lines for pens without and with creep heating (HEAT). The piglets' use of a heated creep was higher and more dependent on outdoor temperature than when the creep was unheated (interaction creep heating x mean outdoor temperature: P = 0.030).

outdoor paddock during the first week of life across seasons can be found in Jahoui et al. (2024).

3.3. Piglet growth

3.3.1. Total weight of live piglets D1, D21, and D49

We found no effect of creep heating or a pendulum on the total litter weight during the study (D1, D21, D49: P = 0.28–0.71). The total weight of the litter increased with sow parity (D1: $F_{1,79} = 7.3$, P = 0.008; D21: tendency $F_{1,74} = 3.0$, P = 0.090; D49: $F_{1,62} = 4.1$, P = 0.047) and with the age of the litter at the actual weighing day (D21: spanned 14–27 days, $F_{1,74} = 39.1$, P < 0.001; D49: spanned 41–57 days, $F_{1,62} = 10.8$, P = 0.002). Further, at weaning (D49), the sows' body condition score decreased as the total weight of her litter increased ($F_{1,62} = 7.2$, P = 0.009).

Season effects on litter weight were evident on D1 ($F_{3,79} = 3.2$, P = 0.027) and D49 ($F_{1,62} = 7.1$, P < 0.001), but not significantly on D21 ($F_{3,71} = 2.0$, P = 0.12). On D1, litters were approximately 20 % heavier in the spring (kg: 24.8 ± 0.93^{a}) than in the winter (20.6 ± 1.19^{b}), with the other seasons being intermediate (summer: 23.2 ± 0.89^{ab}, autumn: 23.6 ± 1.42^{ab}). At weaning (around D49), litters were heavier in both spring (230.2 ± 8.28^{a}) and autumn (234.8 ± 11.58^{a}) than in summer (217.7 ± 6.41^{b}) and winter (199.3 ± 13.49^{b}).

3.3.2. Average daily gain (ADG)

The ADG results are presented for the first three weeks, the last four weeks, and the whole period until weaning. This acknowledges the life stages of piglets, with their gradually increasing independence from suckling the sow; further, transient effects of early creep heating could be present without longer-term impacts on piglet growth.

The first three weeks, D1 to D21. There was a significant interaction between the heating and pendulum treatment ($F_{1,74} = 5.3$, P = 0.024) on the ADG (Table 2), and the ADG was negatively correlated with the number of piglets in the litter ($F_{1,90.4} = 14.5$, P < 0.001). The piglet ADG varied with season ($F_{3,74.4} = 5.3$, P = 0.002), with higher gains during spring (g/day: 255 ± 6^{a}) and autumn (255 ± 8^{a}) than during summer (222 ± 6^{b}) and winter ($232 \pm 8\ ^{b}$), with no significant effect of sow Parity ($F_{1,66.4} = 1.3$, P = 0.26) or being cross-fostered ($F_{1,1085} = 2.7$, P = 0.10).

The higher ADG in piglets in the group with no creep heating and no pendulum (Table 2) may be influenced by a numerically (i.e. not-significantly different) lower number of piglets in the litter for this combination (for creep heating x pendulum, no I no: 12.3 ± 0.21, no I yes: 12.6 ± 0.17, yes I no: 12.8 ± 0.17, yes I yes: 13.6 ± 0.10 piglets, however NS difference); fewer piglets per litter is associated with higher ADG for the individual piglet (P < 0.001).

During the last four weeks until weaning, D21 to D49, the fixed factors did not affect ADG (HEAT P = 0.74; Pendulum P = 0.62; Table 2). Sow Parity had no effect ($F_{1,\ 73.2} = 0.8$, P = 0.36). Like the first three weeks, the ADG correlated negatively with the litter size ($F_{1,80.2} = 26.5$, P < 0.001) and varied with season ($F_{3,76.2} = 4.1$, P = 0.010). Piglet gains were higher during spring (g/day: 386 ± 13^{a}) and autumn ($407 \pm 15\ ^{a}$) than during summer (346 ± 13^{b}), while not different from ADG during winter ($364 \pm 20\ ^{ab}$). Further, foster piglets had lower ADG than piglets born into the litter (360 ± 14 vs 391 ± 7 g/day; $F_{1,1007} = 6.4$, P = 0.012).

During the whole period, D1 to D49, the fixed factors did not affect piglet ADG (HEAT P = 0.35; Pendulum P = 0.94) for the whole period until weaning (Table 2). The ADG decreased with the litter size weaned ($F_{1,64.4} = 38.0$, P < 0.001) and increased with the parity of the sow ($F_{1,59.9} = 4.3$, P = 0.042).

The ADG tended to increase with the decreasing sow BCS at weaning, indicative of some depletion of sow reserves ($F_{1,59.8} = 3.6$, P = 0.061) and varied with the season ($F_{3,60.4} = 7.5$, P < 0.001); ADG was higher during spring (g/day: 321 ± 12^{a}) and autumn ($338 \pm 12\ ^{a}$) than summer (272 ± 11^{b}), but not statistically different from winter ($297 \pm 14\ ^{ab}$). Foster piglets had on average a 14.5 % lower ADG than piglets born into the litter (283 ± 13 vs 331 ± 5 g/day; $F_{1844} = 14.4$, P < 0.001) following the early cross-fostering D1. This effect was not due to a sex bias in the piglets randomly selected for fostering (45 % male, 55 % female vs not fostered piglets: 48 % male, 52 % female).

Further, a post hoc analysis comparing fostered vs non-fostered piglets from large litters only (defined as the number of live piglets

Table 2
Piglet Average Daily Gain (ADG), g/day, for the four treatment groups in the study.

	Creep heating x Pendulum			
	no I no	no I yes	yes I no	yes I yes
First three weeks, D1-D21	252 ±3a	235 ±4b	235 ±4b	239 ±4b
Last four weeks, D21-D49	386 ±5a	384 ±6a	384 ±6a	397 ±7a
Whole period, D1-D49	333 ±5a	326 ±5a	322 ±4a	337 ±5a

Different letters (a, b) indicate statistical differences between groups within periods.

greater than the number of teats, 30 litters) confirmed a lower ADG in foster than in native pigs ($P = 0.020$), without significant difference ($P = 0.58$) in their D1 weight.

3.4. Piglet mortality

3.4.1. Necropsy

Necropsies were performed on dead piglets collected from all the litters allocated to the study at the farm until D21. These data and the sampling record were used to determine whether the piglets were live-born or stillborn. Data on offspring from the experimental litters (n = 88; Table 1) were included in the statistical analysis of live-born mortality as a litter response and the latency of dying for each individual piglet.

3.4.2. The live-born litter mortality

There was no fixed factor effect on the live-born litter mortality from D1 to weaning D49 (Table 1; HEAT $F_{1,78} = 0.4$, $P = 0.54$; Pendulum $F_{1,78} = 0.0$, $P = 0.86$), nor effects of most other variables (D1 litter size, $P = 0.65$; Sow temperament score: $P = 0.48$, Season: $P = 0.12$, Parity: $P = 0.20$). We found markedly increased mortality in litters of the five sows with impaired walking (gait score 1: 37.5 ± 8.77 % vs gait score 0: 15.2 ± 1.15 %; $F_{1,78} = 20.0$, $P < 0.001$).

3.4.3. The latency to death for individual piglets

From birth until weaning around D49, the latency of dying was not different between the factors (HEAT: $\chi^2_1 = 0.2$, $P = 0.69$; Pendulum: $\chi^2_1 = 0.03$, $P = 0.86$). Males (castrated) had a higher risk of dying (Hazard ratio: 1.43, 95 % CI: 1.13–1.82) than female piglets ($\chi^2_1 = 8.5$, $P = 0.004$) during our study period. Further, there was a tendency of increased risk of dying for foster piglets ($\chi^2_1 = 3.0$, $P = 0.085$); i.e. they have a shorter latency for dying than non-foster piglets.

A supplemental analysis with outdoor temperature (D2 mean: −4.0 – 22.9 °C) as a covariate instead of the season in the model did not change the results as the outer temperature did not (creep heating x outdoor temperature: $P = 0.59$, outdoor temperature: $P = 0.84$) influence the latency for piglet dying.

4. Discussion

Newborn piglets face a drop in body temperature immediately after birth, even in controlled indoor environments at a stable temperature of 21 °C (Malmkvist et al., 2006). While this thermal drop normalises for surviving piglets, the risk of adverse and life-threatening hypothermia remains significant, particularly for the smallest piglets and in environments below 20 °C during farrowing (Pedersen et al., 2015). This risk is expected to be more pronounced in outdoor free-ranging production systems where piglets born in farrowing huts can be exposed to lower temperatures, especially during cold seasons in certain regions. In light of these thermoregulatory challenges, our study investigated the effects of creep heating from birth to day 7 in farrowing huts on outdoor paddocks. We examined whether this intervention increased the early creep use by piglets (observed via video on days 0 and 2) and improved their survival and growth rates from birth to weaning. The research included 88 sows and litters across all four seasons on an organic farm in Denmark, representing a temperate coastal climate. We aimed to understand better and potentially mitigate the thermal cold risk faced by piglets in outdoor production systems.

4.1. Piglets' creep use increased with heating

During the first day of life (D0), creep usage was low regardless of whether it was heated. The position of the sow (rump facing the creep) at birth – rather than the creep temperature – facilitated the first creep entry by piglets. The low use of the creep on D0 in outdoor farrowing huts aligns well with findings in indoor climate-controlled stables (Vasdal et al., 2010). For example, one previous study showed that only a few piglets use warm areas away from the sow during their first day of life, tested at room temperatures of 19 °C in indoor stable pens with heat lamps (Hrupka et al., 1998).

The proportion of the piglets in the creep increased on D2, averaging 28 % of the 24 h of observation for the heated creeps. Thereby, piglets were observed four times more often in a heated creep than if the creep was unheated. Further, the piglets' preference for a warmer place increased with colder weather, ranging from −4–23 °C as daily mean outdoor temperatures in our study. Thus, young day 2 piglets are attracted to a heated creep, especially during colder outdoor temperatures.

Despite the addition of creep heating, the proportion of the piglets at the sow's udder remained unchanged. This suggests that the time spent at the udder (D0 and D2) represents a fundamental and inflexible behaviour in young piglets, unaffected by the presence of a warm zone away from the sow. It is established that piglets benefit from close contact with the sow for thermoregulation and colostrum intake during their first days of life (Algers and Jensen, 1990; Algers, 1993; Herpin et al., 2002). Our findings support the notion of Hrupka et al. (1998) that only after the first day of life, as piglets gradually mature and move around more, does supplementary heating become a way of attracting them to a designated creep area.

When activated, the heating lamps used in our study emitted visible light into the creep area and adjacent part of the pen. However, results indicate that visible light does not attract piglets into creep areas, based on comparisons between creeps with and without light-emitting heat sources in Larsen et al. (2017). In fact, their findings suggest that visible heating lamps may be less effective than radiant heating in attracting piglets, tested in a 20 °C indoor stable (Larsen et al., 2017). Therefore, we suggest that future studies investigating creep heating – also in the harsher outdoor hut environment – consider alternative heat sources to traditional heating lamps. Options such as floor heating mats could prove more effective while maintaining natural darkness inside the creep and the housing hut. It is currently unknown whether an additional light source may disturb the natural rhythms or sleep quality of sows and piglets during dark phases.

Our study revealed that piglets' stay in the heated creep area decreased with increasing outer temperatures, as illustrated in Fig. 3. A dependency of outer temperature on the piglet preference for warmer creep has been reported in one indoor study (using farrowing room temperatures fixed at 15, 20, or 25 °C in Pedersen et al., 2013), but to our knowledge, not previously documented in outdoor huts. Most reports on piglet behaviour are based on indoor studies, where ambient temperatures are typically maintained at 19 °C or higher at farrowing (Hrupka et al., 1998; Vasdal et al., 2010; Larsen et al., 2017). This insight underscores the importance of conducting studies in diverse environmental conditions, including outdoor settings, to understand piglet thermoregulatory behaviour during the early, critical days of life.

4.2. Piglet survival and growth

4.2.1. Influence of heating

We found no significant effect of creep heating on survival and growth based on weighing each piglet individually at D1, D21, and around D49. Transiently, ADG was higher in the no heat/no pendulum treatment group during the first three weeks, which we speculate may relate to reduced within-litter competition due to more piglets lost and consequently a lower litter size in this treatment (raw data, not statistically significant different litter size between groups in our study of 88 litters).

These insignificant results contrast with our expectations. Malmkvist et al. (2006) reported that floor heating (at 34 °C) nearly halved the piglet mortality observed during the first week in loose-housed 2nd parity Danish Landrace x Danish Yorkshire sows kept indoors at 21 °C. In the following part of the discussion, we consider three main reasons for the lack of significant effect on piglet survival following the heating intervention in the current study:

Firstly, the previous study enhancing survival exposed the piglets to a 34 °C warm surface at birth via on-site floor heating. In our current study, piglets had to move into the creep to benefit from the artificial heat source. The recovery from temperature drop is reported within the first 12 (Malmkvist et al., 2006) or 8–24 h (Pedersen et al., 2015), during which creep use was only 2.6 % of the D0 observations. Thus, although piglets born in outdoor huts may benefit, they remain practically unexposed to heating during the critical period (D0) after birth, when provided in the creep area.

Secondly, factors other than hypothermia influence piglet mortality (Edwards, 2002). Outdoor huts on farms represent a variable environment, with more fluctuating temperatures than in the indoor studies. We addressed this variation by enrolling 88 litters across seasons, with all treatments present in each hut of four sows. We aimed at a higher number of replications, but some litters were excluded due to a late onset of the heating (done manually by the farmer) and periodical loss of electricity in the huts. Further, 5.7 % of the sows were recognised as sick, with a mortality rate of 2.3 %. Thus, we cannot exclude that illness and impaired gait result in additional piglet mortality, overshadowing a potential effect of creep heating. We included sows of different parities (from 1 to 8) having the approximate same expected day of farrowing when moved to the test hut; we expect sow parity to influence mainly the number of stillborn (Thorsen et al., 2017) and to a lesser extent the risk of dying later (increased mortality reported for sow parity five vs 1–4 in Kobek-Kjeldager et al., 2023a; but reduced mortality for sow parity 3–6 vs 1–2 in Hales et al., 2013). Accordingly, the mortality of liveborn piglets was not impacted by sow parity in our study. Altogether, the study is among the largest of its kind to investigate thermal conditions; although associated with multiple sources of variation, this is a relevant reflection of on-farm conditions.

Thirdly, the total piglet mortality before weaning, including stillborn, was lower at the studied farm (19.0 %) than previous findings in outdoor herds (29.5 %) in Denmark (Rangstrup-Christensen et al., 2018). This may be due to the TN70 type sow used on the current farm, whereas DanBred sows were used on all farms in the earlier study by Rangstrup-Christensen et al. (2018). Larger litters are associated with smaller-sized, weaker piglets being more prone to hypothermia and early mortality (Rutherford et al., 2013; Schild et al., 2020a). The TN70-type sows have been suggested as more suitable for outdoor production due to heavier piglets (at birth and weaning) and a lower mortality rate from birth to weaning (Kobek-Kjeldager et al., 2023b; Schild et al., 2020b). However, the litter size in the current study using type TN70 sows was not low: an average of 16.5 D1 across parities; thus, equal to or slightly higher than in a previous study by Malmkvist et al. (2006), which demonstrated increased piglet survival following floor heating at birth in 2nd parity DanBred type Landrace x Yorkshire sows. Another factor to consider – but not possible to test as our study only contained one type of hut – is the climate protection provided by the recently developed mobile hut holding four sows. Perhaps these huts offer better climate protection than the single-sow ‘A-hut’ commonly used in Danish outdoor pig production. Consequently, we cannot exclude that additional heat might enhance piglet survival rates in less sheltered huts/more adverse climate conditions than in the current study.

Our study shows that organic outdoor production using farrowing huts can occur without exceeding the piglet mortality reported for conventional indoor housing in the same country.

4.2.2. *Other factors affecting piglet survival and growth*

The risk of dying from birth to weaning was significantly higher in the males (castrated day 3–7 after birth) than in female piglets. It is currently unknown whether this difference in survival relates to sexual dimorphism or is a consequence of the surgical castration of the males. At least, some evidence for a sex bias in the mortality of pigs exists. Newly weaned females (i.e., gilts) may also exhibit lower mortality rates than castrated or intact males, according to Pluske et al. (2019) (no data presented). A detailed study of litters under outdoor conditions (based on fewer farrowings, n = 36) suggested a poorer thermoregulatory ability in newborn males (Baxter et al., 2012). This hypothesis warrants further investigation, as it is based on less clear trends in the results on rectal temperatures (D0). Regardless of the mechanisms involved, more male than female piglets died before weaning in this outdoor study by Baxter et al. (2012). Accordingly, higher male than female piglet mortality was reported across outdoor Danish farms until weaning at 7 weeks (Rangstrup-Christensen et al., 2018). Data from 3402 piglets from 203 sows housed in indoor pens (using surgical castration D4 and early weaning at 4 weeks) reported increased mortality likewise in males and increased survival with a greater body weight and if born from older sows (Hales et al., 2013). In our study, the sex bias in mortality was absent until the day of castration (proportion: 50 % males and 50 % females of the dead piglets). On the day of castration, 80 % of piglets collected as dead were males, remaining to be the overrepresented sex with a proportion of 63 % for the remaining post-castration period until weaning. Admittedly, these observations are based on a low number of dead piglets (65 with exact known castration date) and thus prone to randomness; however, they still support the concern that surgical castration poses a life-threatening risk for piglets, at least during the studied conditions. More extensive and targeted studies are needed to investigate the risk of castration, as this procedure is a stressor (e.g., Coutant et al., 2022) and is currently sustained in the production of pigs in several places worldwide, including in Denmark. Thus, besides the negative welfare implications, any management-induced surplus mortality burdens farmers’ production efficiency.

In addition to a sex bias, there were signs of increased death risk in foster than in native piglets (tendency, $P = 0.085$). Further, foster piglets had significantly lower growth rates from D1 to weaning (14.5 % lower average daily gain than native piglets of the litter; $P < 0.001$). In a herd-level study (241 litters, of which approximately 30 % were affected by cross-fostering), the odds for antibiotic treatment during the suckling period was 1.6 in cross-fostering litters (Nielsen et al., 2022). These results are not directly comparable to our findings as piglets in Nielsen et al. (2022) were not individually followed (whole litter results), and sending vs receiving litters were not differentiated in their study. Previous results have shown that hypothermia at birth, low birth weight, and a high number of piglets reduce average daily gain during the suckling period (Pedersen et al., 2015). In contrast, the effect of early cross-fostering appears less well-studied. As foster piglets originate from larger litters (number of live piglets greater than the number of teats), fostering may be confounded with litter and piglet size D1; as expected, fostered piglets are on average (83 g, equivalent to 5.8 %) lighter than non-fostered piglets recorded across all 88 litters sizes on D1. However, comparing fostered vs non-fostered piglets from large litters only (defined as the number of live piglets greater than the number of teats, 30 litters) confirmed a lower ADG in foster than in native pigs, having equal body weight on the day of transfer to another sow. The surplus piglets to be fostered were selected randomly in large litters. Thus, we consider the negative effect of ADG to be induced by fostering, rather than by a lower body weight. Reduced ADG was also reported in fostered piglets belonging to one of the three weight classes considered (‘high birthweight’: >0.8–1.15 kg) in a study of 20 litters of purebred Chinese Luchuan pigs (Zhang et al., 2021). In line with our findings, King et al. (2020) reported lower ADG until weaning Day 28 (i.e. three weeks shorter nursing period than in our study) in fostered than non-fostered piglets in indoor crates or pens. Further, cross-fostering reduced parts of sow nursing behaviour in this study (King et al., 2020).

4.3. *Conclusion*

Heating resulted in more piglet use of the creep on D2, resulting in fewer observations of piglets scattered in the open part of the farrowing pen. These results demonstrate that creep heating influences piglet site choice early in life – but not on the day of birth (D0), during which the creep use was low – in the farrowing huts. The piglets' use of the creep was higher and dependent on outdoor temperature when the creep was heated, tested at an average daily outdoor temperature between −4 and 23 °C. We did not find significant effects of early creep heating on piglet survival and growth from birth to weaning in this outdoor organic production. The piglet mortality was markedly higher for the few sows with gait problems. Further, the piglet growth and survival were reduced in males (surgically castrated day 3–7) and for fostered piglets (cross-fostered day 1) during the suckling period.

CRediT authorship contribution statement

Jens Malmkvist: Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Lene Juul Pedersen:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Cecilie Kobek-Kjeldager:** Writing – review & editing, Supervision, Methodology, Investigation.

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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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.applanim.2025.106794.

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