# USE OF THERMOGRAPHIC TECHNOLOGY TO DETECT REPRODUCTIVE STATE IN SOWS AND IMPROVE PIGLET PERFORMANCE IN A COMMERCIAL FARROWING HOUSE

## 6A-104

**Final Report prepared for the Australasian Pork Research Institute Limited (APRIL)**

**By**

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# Executive Summary

Thermal imagery is becoming relatively cheap and is a non-invasive and easy-to-use on-farm tool that can be used to measure skin temperature and may help to predict reproductive state and health challenges in sows and piglets. The current project aimed to assess the use of infrared thermography (IRT) in a commercial farrowing house to predict sow and piglet performance in lactation as well as identify sows at risk of common health concerns in lactation, such as mastitis, shoulder sore formation and other illnesses.

Two experiments were conducted in this project. Experiment 1 was a pilot experiment to assess two separate IRT camera technologies and a number of locations on the sow for skin temperature measurement, for their ability to detect reproductive performance and/or health issues in lactating sows. The camera technologies used were the FLIR Systems E8 Ex Series handheld camera and the FLIR Systems ONE Pro iPhone attachment (FLIR Systems, Wilsonville OR, USA), and skin temperature measurements were taken from the eye, ear base, ear tip, whole udder, anterior teats, posterior teats, shoulder, snout and vulva. Images were taken from 41 sows (parities 2 to 7) with both cameras of all locations (where possible) on days 1, 9 and 16 after farrowing 3 times a day. Skin temperatures were measured via the on-screen pointer and averaged over the whole image, extracted using Matlab software (R2018b; Mathworks Inc, Natick, MA, USA), and a number of sow performance and health parameters were studied. Skin temperatures (eye, ear base and ear tip) in piglets were also examined around birth in this experiment. Relationships between pointer and extracted temperatures were well correlated for most measures taken in Experiment 1, and hence only pointer temperature was taken for Experiment 2 as this was easier to obtain in a commercial setting and can be taken at the time of measurement.

From Experiment 1, the FLIR E8 Ex Series camera was selected as the most appropriate camera for commercial use and the ear base, shoulder and posterior teats were selected as the skin temperature regions with the most commercial relevance to further assess on a commercial scale in Experiment 2. Images were taken using the E8 camera from 270 sows (parity 2 to 6) of the ear base, shoulder and posterior teats once a day, 3 times per week from each sow. Temperature measured by the pointer on the camera screen was recorded for each image and compared to a number of sow performance health parameters.

In both experiments it was shown that skin temperatures were greatly influenced by ambient shed temperature. Several skin temperatures were well correlated with each other, especially those of the ear base, shoulder and posterior teats. Skin temperatures showed mostly weak correlations with rectal temperature in sows; however, skin temperatures showed promise as an alternative method to detect a high temperature (fever) in sows (>38.5°C in our analysis). In piglets, the correlation between skin temperature at the ear base and rectal temperature was higher than it was in sows, but this was not the case for ear tip skin temperature. Eye temperatures (extracted from the whole image using the Matlab software) showed relationships with colostrum intake in piglets in the first 24 h of life, with higher temperatures in piglets consuming ≥ 200 g of colostrum. However, there was no significant relationship between any skin temperatures studied and piglet serum immunocrit at 24 h of life.

Some skin temperatures (e.g., posterior teat, shoulder and vulva temperature) were related to litter size, where they were shown to be significantly higher in sows having ≤13 piglets born alive than in those having >13 born alive. This may be related to increased activity around farrowing in sows with higher litter sizes (shoulder skin temperature) or increased

activity of piglets around the udder (posterior teat skin temperature) and requires further investigation.

During Experiment 2, the commercial farm suffered an outbreak of Japanese Encephalitis Virus (JEV). Sows were identified as having suffered from JEV if piglets were born shaking, litters had an abnormally high incidence of stillbirth, and/or sows exhibited a prolonged gestation where farrowing was required to be hormonally induced. In sows that were identified as having JEV, ear base, shoulder and udder skin temperatures were all elevated in the 2 weeks prior to farrowing and the week of farrowing compared to those that weren't impacted by JEV. This indicates that skin temperatures in sows before farrowing may be useful for identification of JEV infection before the presentation of clinical signs and deserves to be further investigated.

Meaningful and significant relationships were not found between skin temperatures and the incidence of shoulder sores and/or the incidence of mastitis in sows in this project, as was originally hypothesised. However, previous authors have used IRT to detect "hot spots" on sow shoulders during lactation for early identification of shoulder sore formation, and hot spot incidence was not recorded in the current study. Furthermore, absence or presence of mastitis was identified in the current study as any clinical signs of mastitis seen in at least one teat in the udder (e.g., swelling, redness, discharge from the teat etc.) and scorer was not controlled for, which may have influenced the outcome. The relationships between sow skin temperatures and shoulder sore formation and mastitis incidence should be further investigated in future studies.

In conclusion, data extracted from IRT images taken using a thermal camera must not be used alone to detect or predict sow health status and/or reproductive performance in a commercial farrowing house. Skin temperatures measured using the handheld devices utilised in this project were not sensitive enough to detect sows at risk of lowered production in the farrowing house. However, skin temperatures measured using IRT may offer a non-invasive way to measure sow and/or piglet temperatures if rectal temperatures are not able to be collected. To be truly informative in a commercial farrowing house, IRT should be used in conjunction with measurement of other environmental factors, such as ambient temperature, humidity, cleanliness of the body area being measured, etc., and algorithms developed to use these factors to better predict sow performance. Remote monitoring using real-time IRT methods may be a better application for these technologies in a commercial farrowing house.

Regardless, skin temperatures measured by IRT at the ear base, shoulder and udder may be more informative regarding sow reproductive performance and health status in a commercial farrowing house. These relationships deserve to be further investigated.

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# 1. Introduction

Infrared thermography (IRT) is becoming relatively cheap and is a non-invasive and easy-to-use on-farm tool that may be used for predicting reproductive state and health challenges in sows and piglets. A number of studies have investigated several locations for thermal image detection of skin surface temperature (reviewed by Soerensen et al., 2014) in growing pigs, but few have looked at different areas in breeding sows.

Further assessment of these skin temperatures measured by IRT in relation to sow reproductive and health outcomes and viability of piglets at birth is required. If IRT technologies can be used to indicate poor health and/or welfare of sows in the farrowing house, their milking potential and success in lactation, or whether a piglet is likely to survive shortly after birth and until weaning, this would allow for better management of sows and their piglets in lactation. This technology could be used to identify the milking potential of sows, neonatal piglets that require assistance shortly after birth, and as an early diagnosis tool for health issues such as mastitis or shoulder sores. Identifying mastitis or other health problems in sows would allow early intervention in these animals. Moreover, this would allow their piglets to be managed accordingly to maximise their pre-weaning performance. This would also have overarching benefits to the welfare of sows and piglets, which is a prominent issue in the minds of the consumer.

The current project aimed to examine a number of locations for skin surface temperature measurement that have recently been shown to be correlated with measures of animal reproductive performance, such as the udder (which has been linked to the incidence of mastitis in dairy cows; Sathiyabarathi et al., 2016), vulva (which has been used to assist in detection of oestrus in sows and other species; Sykes et al., 2012; Stelletta et al., 2017), tip and base of the ear and eye (which have been well correlated with rectal temperature in sows; Soerensen and Pedersen, 2015), and shoulder (which may be useful in prediction of shoulder sore formation; Westin and Rydberg, 2010; Staveley et al., 2022). Moreover, thermal imaging has been successfully used to assess the viability of piglets at birth (Santiago et al., 2019) and, therefore, may be a good indicator of their ability to access colostrum, which we aimed to further investigate.

FLIR Systems Inc. (USA) have developed several thermal imaging cameras that can be easily used on farm and are commercially available for purchase in Australia at a reasonable cost for producers. Two such devices are the FLIR Systems E8 Ex Series camera, and the FLIR ONE Pro iPhone/Android attachment. These devices are small and compact and can measure thermal signatures in real time whilst capturing photographs for further analysis. This project aimed to use these two cameras to evaluate their effectiveness in a commercial farrowing house environment and relate readings from these devices to sow and piglet performance in lactation.

Firstly, a pilot study (Experiment 1) was carried out to determine the best camera for use to assess sow and piglet productivity and health status via IRT in the farrowing house, and the best locations to take these measures on the sow. Secondly, a larger commercial experiment (Experiment 2) was conducted to further evaluate the use of the best thermal camera and areas for skin temperature measurement selected from Experiment 1 in a commercial setting.

From these two experiments, it was hypothesised that:

(1) Skin temperatures would be highly positively correlated with rectal temperature and hence offer a non-invasive alternative for measuring body temperature in sows;
(2) Skin temperatures would be highly correlated with reproductive performance and health status of sows;
(3) Skin temperatures (specifically udder temperature) would show a high positive correlation with milk production (litter average daily gain and weight at weaning) and incidence of mastitis in lactating sows;
(4) Skin temperature of the shoulder would be significantly higher in sows that developed shoulder sores in the days leading up to the sore appearing, compared to sows that did not develop a shoulder sore in lactation; and,
(5) Skin temperatures would be highly positively correlated with rectal temperatures in piglets at birth and indicate their ability to consume colostrum in early life.

# 2. Methodology

## *2.1 Experiment 1: Pilot study*

### a) Animal welfare statement

All experimental procedures were approved by the Rivalea Animal Ethics Committee (protocol number 20R047C) in accordance with the Australian code for the care and use of animals for scientific purposes (National Health and Medical Research Council, 2013).

### b) Experimental design

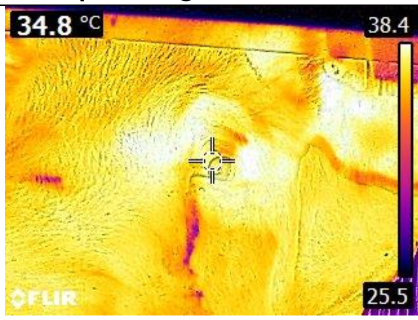
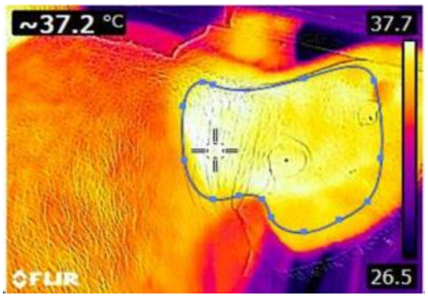
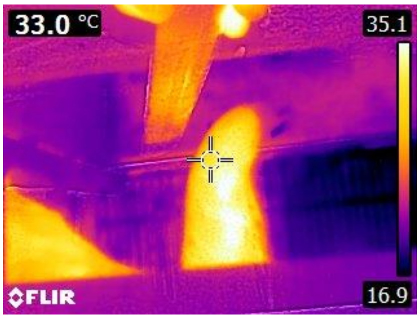
The experiment was carried out at a commercial breeder facility (Corowa NSW, Australia) between February and April 2021. A total of 40 sows (parity 1 to 6 at entry to the farrowing house; Primegro Genetics, Corowa, NSW) housed in a conventional crated farrowing system (slatted floor farrowing crates; crate 0.5 x 2.0 m, pen 1.6 x 2.0 m) were included in the study. Sows were moved to the farrowing house at 110 ± 1 d of gestation. Each pen was equipped with sow and piglet nipple drinkers, and a solid floor creep area with an electric heat lamp positioned centrally over this area. The accommodations were semi-enclosed, naturally ventilated and included a dripper cooling system set to activate at 28°C. For additional temperature control on hot days, portable evaporative coolers were placed in the shed at entry and used for 2 weeks after farrowing.

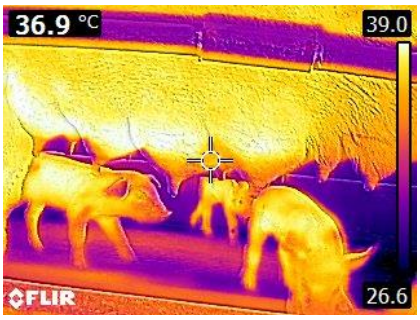
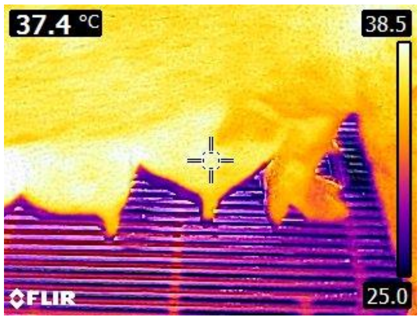
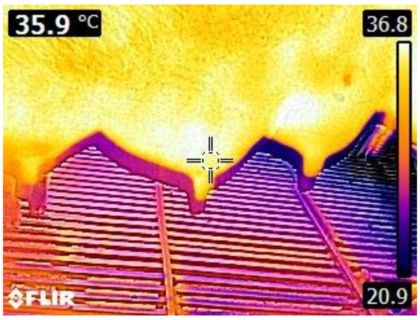
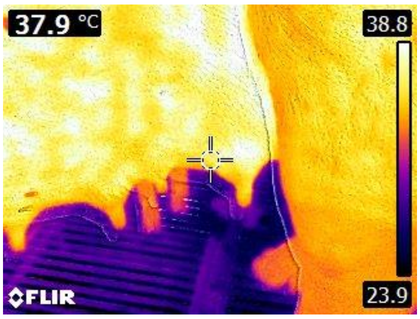
Thermal images were taken using two different IRT technologies (described above) to obtain the skin temperature of the sow and piglets at various locations on the body. Ambient temperature of the shed was collected using a temperature logger. The average skin temperature from the location of interest was extracted from the thermal infrared images in Matlab® R2018b (Mathworks Inc, Natick, MA, USA) using the method reported by Jorquera-Chavez et al. (2020).

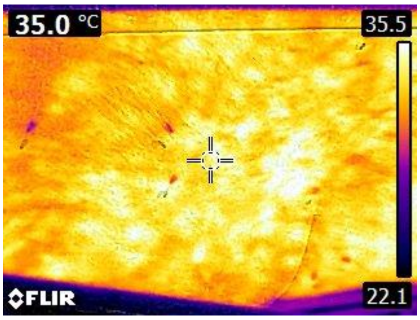
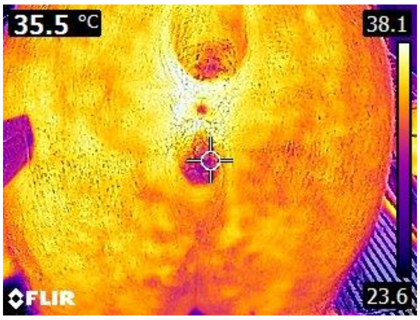
## c) Sow measures

For each sow, the following was recorded: gestation length, number of piglets born alive, born stillborn and total piglets born, litter weight post-fostering, litter weight and number at weaning (30 ± 6.9 d of age), and wean to remate interval (WRI). Thermal images and rectal temperatures of sows were taken on day 1, 9 and 16 after the farrowing date. Where possible, images were taken from the same distance from the sow (30 cm, using a ruler as a guide). Rectal temperatures were measured on each sow at the same timepoints using a rectal thermometer. Images were obtained from a number of locations on the sow, described in Table 2.1.1.

**Table 2.1.1:** Description and example of the number of regions that skin temperature was measured on the sow in Experiment 1.

| Area | Description | Example Image |
|---|---|---|
| Eye | Taken of the open eye (either side), from in front or above the sow depending on whether she was standing or lying. |  |
| Ear base | Taken at the base of the ear (either side), from behind the sow. |  |
| Ear tip | Taken of the very tip of the ear (either side) from above or in front of the sow depending on whether she was standing or lying. The example image shows difficulties with locating the very tip of the ear with the camera pointer. |  |

| | | |
|---|---|---|
| Whole udder | Taken of all active teat pairs on either side of the sow. Taken from above or to the side of the sow depending on whether she was standing or lying. The example image shows difficulties of interference from piglets. |  |
| Anterior teats | Taken of the front one or two teats (either side) with the pointer on the foremost active teat. Teat was considered active if the gland had a ‘full’ appearance and milk could be expressed. Taken from above or to the side of the crate depending on whether she was standing or lying. |  |
| Middle teats | Taken of 3 of the middle teat pairs (either side). Taken from above or to the side of the crate depending on whether she was standing or lying. If there were 2 middle teat pairs, 1 pair was selected at random for the pointer temperature and the image taken at this location. |  |
| Posterior teats | Taken of the back one or two teats (either side) with the pointer on the back-most active teat. Taken from above or to the side of the crate depending on whether she was standing or lying. |  |

| | | |
|---|---|---|
| Shoulder | Taken of either shoulder just above the area where the front leg joins the body. Taken from above or to the side of the crate depending on whether she was standing or lying. Farrowing crate bars were kept out of the image where possible. |   |
| Snout | Taken of the surface of the snout with the pointer aimed at the middle of the snout where possible. Taken from in front or to the side depending on movement of the sow. Example image shows difficulties in capturing the snout skin temperature with movement of the sow and obstructions from the farrowing crate. |   |
| Vulva | Taken of the middle of the vulva, where possible. Taken from behind the farrowing crate with sow standing up, with the image taken straight on from the vulva. |   |

## d) Piglet measures

In total, 109 piglets (53 male and 56 female) born to six of the experimental sows (parity 3.5 ± 1.16; 1 to 4 at entry to the farrowing house) were used for investigating skin temperatures and performance variables in individual piglets.

The time of birth was recorded for each piglet, who was then weighed, and thermal images were taken to measure the surface temperature at the base of the right ear, the tip of the right ear and the right eye (Fig. 2.1.1). Rectal temperature was taken immediately after the thermal images were obtained using a standard digital thermometer, and piglets were tagged and returned to the same position in the crate they were removed from. At 24 h after birth, piglets were reweighed, skin temperatures were recorded at all locations, and rectal temperature was recorded. Any mortalities between birth and 24 h were recorded.

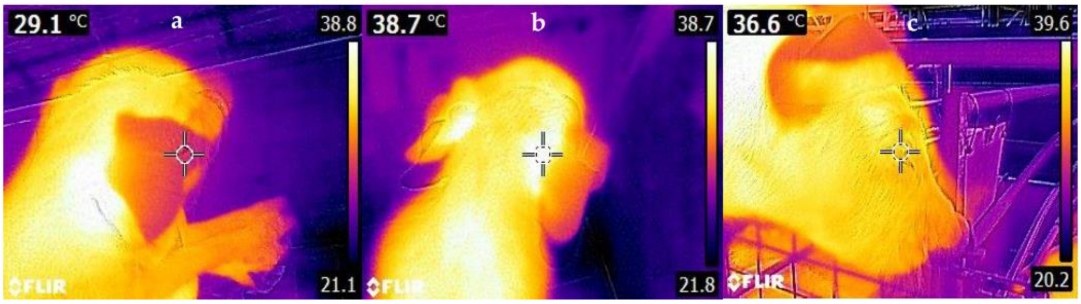



**Fig. 2.1.1:** Examples of thermal images taken of different surface locations obtained from piglets with the FLIR E8 camera: (a) ear tip, (b) base of ear and (c) eye (adapted from Tucker et al., 2023).

Colostrum intake was calculated for each piglet using the equation developed by Devillers et al. (2007):

$$CI = -217.4 + 0.217 \times t + 1861019 \times \frac{W}{t} + BW \times \left(\frac{54.8 - 1861{,}019}{t}\right) \times (0.9985 - 3.7 \times 10^{-7} \times t_{fs}^{2})$$

where CI = colostrum intake (g), W = piglet body weight at 24 h (kg), BW = piglet body weight at birth (kg), t = age (min), and $t_{fs}$ = time elapsed from birth to first sucking (min); $t_{fs}$ was assumed to be 30 min and t was 1440 min (24 h). Additionally, piglets were categorised (CL1: < 200 g, CL2: ≥ 200 g) based on their colostrum intake, with 200 g being the recommended minimum amount of colostrum needed to maximise the chance of survival to weaning (Quesnel et al., 2012).

Additionally, a cohort of piglets were blood sampled within 24 h of birth (*n* = 56) via jugular venepuncture into vacuum blood tubes containing clot activator (BD Vacutainer, Franklin Lakes NY, USA). Tubes were spun at 5,500 x *g* for 15 min and serum was frozen at -20°C until later analysis. Serum samples were analysed for immunocrit (%) as per the methods of Vallet et al. (2013).

## e) Statistical analysis

From each thermal image the skin temperature at the centre point on the camera was indicated on the camera screen when the image was taken, and this was recorded and referred to as the "pointer value". Infrared thermal images were further analysed using MATLAB® R2020 (MathWorks Inc. Natick, MA, USA) and FLIR® Atlas SDK (FLIR Systems, Wilsonville, OR, USA; Jorquera-Chavez et al., 2021b). The desired location of interest was selected using this software, which allowed extraction of the maximum temperature from the desired location ("extracted value").

Correlations were made between continuous variables using simple Pearson's correlation analysis and compared using the PROC CORR procedure within SAS (SAS Institute Inc, Cary NC, USA). Correlation was deemed very high if $R^2$ ≥ 0.90, high if $R^2$ = 0.70 to 0.89, moderate if $R^2$ = 0.50 to 0.69, low if $R^2$ = 0.30 to 0.49, and negligible if $R^2$ < 0.30 (Hue et al., 2021). Correlation analysis was conducted for relationships between piglet temperatures, vitality and immunocrit ratios using Microsoft Excel (Microsoft, Redmond WA, USA). Sows and piglets were grouped into 2 or more groups based on their various performance measures, described in section 3 below. Comparisons in skin temperatures at certain timepoints were then made between the two groups using ANOVA (JMP, SAS Institute Inc, Cary NC, USA).

## *2.2 Experiment 2: Commercial evaluation of the FLIR E8 camera*

### a) Animal welfare statement

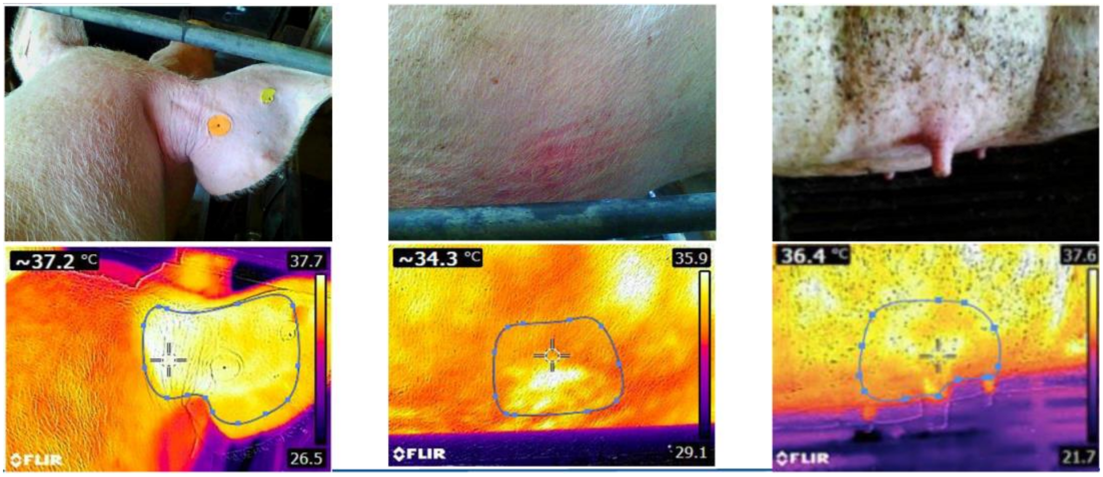
All experimental procedures were approved by the Rivalea Animal Ethics Committee (protocol number 21-023) in accordance with the Australian code for the care and use of animals for scientific purposes (National Health and Medical Research Council, 2013).

### b) Experimental design

The experiment was carried out at a commercial breeder facility (Corowa NSW, Australia) between February and August 2022. A total of 240 sows (parity 2 to 6; Primegro Genetics, Corowa, NSW) housed in a conventional crated farrowing system (slatted floor farrowing crates; 0.5 x 2.0 m) were included in the study. Sows were moved to the farrowing house at 109 ± 2 d of gestation. Pen and shed conditions were like those in Experiment 1. Ambient temperature of the shed was collected using a temperature logger.

Data was collected over six experimental replicates, one batch of sows per replicate. An outbreak of Japanese Encephalitis Virus (JEV) occurred during the experimental period and as a result $n$ = 28 sows required PGF-2α to assist with farrowing, $n$ = 28 sows had no piglets born alive after farrowing, and $n$ = 20 litters were noted to be showing signs of JEV (piglets born shaking, farrowing difficulties, piglets stillborn or mummified, etc.). Therefore, a seventh replicate ($n$ = 30 sows) was added to make up for the piglets affected by the virus.

Skin temperatures were measured with the E8 Ex Series camera using the temperature at the pointer on the screen. The pointer was aimed at the region of interest. Skin temperatures were taken on most days from entry to the farrowing house until the end of lactation at the base of the ear (either side), shoulder (either side) and the posterior teats (both sides; Fig. 2.2.1). For each sow, images were taken 3 times per week, one group of sows on Monday, Wednesday, Friday, and the other group of sows on the Tuesday, Thursday, and Saturday to allow for labour requirements.




**(a)** **(b)** **(c)**

**Fig. 2.2.1:** Visible and infrared images showing the three regions of interest in Experiment 2: (a) ear base, (b) shoulder, and (c) posterior teats.

For each sow and litter, daily sow feed intake was recorded throughout the lactation period (sows were restricted to 2.5 kg of feed per day before farrowing). Sow liveweight and P2 backfat at entry to the farrowing house and at weaning, number of piglets born alive, born stillborn and total piglets born, litter weight and number after fostering (day 1) and at weaning at day 29 (± 3.5 d) of lactation, all piglet mortalities, sow medications and removals were all recorded. It was also noted whether any sows were experiencing farrowing difficulties or required farrowing assistance, any incidence (yes/no variables) of mammary oedema, mastitis or other udder abnormalities or shoulder sores (presence of scar tissue at the point of the shoulder). Mastitis was identified in the current study as gross lumps or localised swelling and/or redness in the mammary gland.

## c) Statistical analysis

For sow health and production performance, days of measurement were divided into weeks relative to farrowing (farrowing being 0). A linear mixed model with repeated measures was used within the MIXED procedure of SPSS (SPSS Statistics v27, IBM, Armonk NY, USA) using an unstructured repeated covariance type. Average skin temperature of all the images taken at each timepoint at the location of interest was modelled as the dependent variables. Sows were split into two or more groups based on their reproductive and health outcomes, similar to the analysis done in Experiment 1. Temperature was then compared between these groups over each timepoint (repeated measure), i.e. the final model used was average skin temperature = measure of interest (fixed) + timepoint (week; fixed) + measure*timepoint (fixed). The COMPARE function within the MIXED procedure was used to make pairwise comparisons between the 2 groups of the measure of interest to compare between groups at each timepoint.

# 3. Outcomes

## *3.1 Experiment 1: Pilot study*

Average performance data of the experimental sows are presented in Table 3.1.1. Images taken of the ear tip and snout of the sow were excluded from the analysis due to the high incidence of operator error. Image quality taken of these locations was low and interference from other factors from the sow's environment was high when trying to record skin temperatures from these locations (e.g., obstructions from pen bars, piglets, sow movement, feed and faeces etc.) and hence meaningful conclusions could not be drawn from the data (see examples in Table 2.1.1).

**Table 3.1.1:** Descriptive statistics for performance data of sows involved in Experiment 1.

| | Statistic | | | | |
|---|---|---|---|---|---|
| Variable | n | Min | Max | Mean | SE |
| ***Sows*** | | | | | |
| Parity at farrowing | 41 | 2 | 7 | 3.0 | 0.19 |
| Gestation length (d) | 41 | 113 | 117 | 114.9 | 0.17 |
| Entry to farrowing (d) | 41 | 1 | 8 | 5.3 | 0.29 |
| Born alive | 41 | 1 | 19 | 12.4 | 0.48 |
| Stillborn | 41 | 0 | 4 | 0.7 | 0.17 |
| Total born | 41 | 1 | 20 | 13.6 | 0.55 |
| Litter weight post-foster (kg) | 34 | 12.4 | 26.7 | 18.0 | 0.60 |
| Litter number at wean | 41 | 5 | 14 | 10.5 | 0.29 |
| Wean to remate interval (d) | 17 | 4 | 6 | 4.6 | 0.17 |
| ***Piglets*** | | | | | |
| Birth weight (kg) | 78 | 0.65 | 2.24 | 1.41 | 0.381 |
| Weight at 24 h (kg) | 75 | 0.53 | 2.33 | 1.52 | 0.430 |

### a) Relationships between different temperature measurements

Correlations were analysed between a number of the variables evaluated in this study. Herein, results presented in the text are least square means ± standard error (SE). Overall, the analysis did not show great correlations between the (extracted) temperature variables studied. The most relevant correlations were between the different areas of skin temperature measured in sows, which were moderate. An example of this is the correlation that was observed between the ear base temperature and the eye temperature of sows during lactation ($R^2 = 0.60$, $P<0.001$; Fig. 3.1.1). The correlation between these temperatures could have been affected by the amount of time in between when the images of each area were collected (i.e., the collection of images for each area would take 30 to 60 sec, so the time between rectal temperature recording and taking of the first images could have been up to 5 to 10 min).

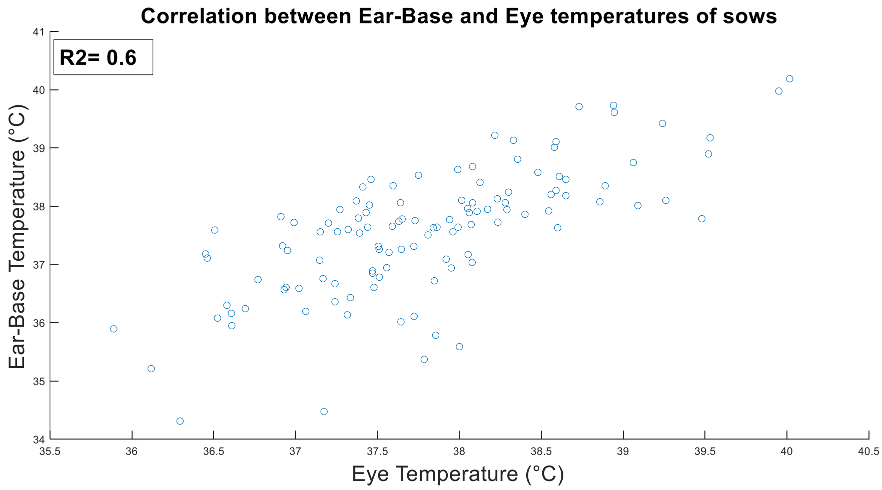



**Fig. 3.1.1:** Correlation between the eye temperature (x) and ear base temperature (y) of sows during lactation.

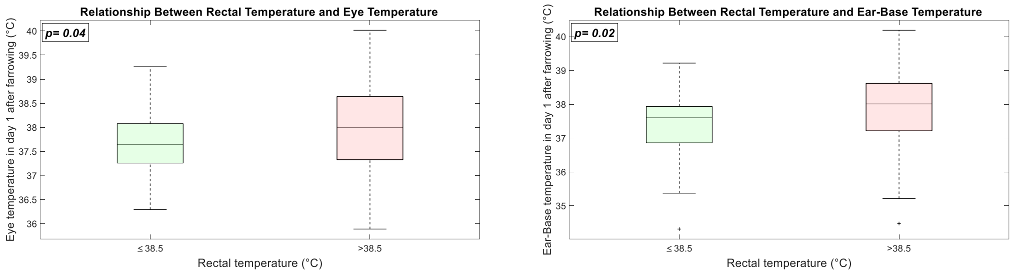
As there were no high correlations observed between variables, the participating sows were divided into groups based on the hypotheses tested and ANOVA analyses were performed to identify differences of skin temperatures between the relevant groups. A number of *post hoc* hypotheses were then tested from the data obtained in this pilot experiment, which are presented below.

Although correlation analyses between rectal, shed and skin temperatures showed low to moderate correlations, results of the ANOVA analyses suggested a considerable relationship between rectal and shed temperatures and the eye and ear base temperatures of sows.

*Relationship between rectal and skin temperatures*
Both eye ($p$ = 0.04) and ear base ($p$ = 0.02) temperature were significantly lower in sows when their rectal temperature was ≤38.5°C than when their rectal temperature was >38.5°C on day 1 of lactation (Fig. 3.1.2). Eye temperature averaged 37.7 ± 0.65°C when sows had a rectal temperature of ≤38.5°C, and 38.0 ± 0.96°C when sows had a rectal temperature >38.5°C ($p$ = 0.04; Fig. 3.1.2a). Similarly, ear base temperature was 37.4 ± 0.88°C when sows had a rectal temperature of ≤38.5°C and 37.9 ± 1.25°C when sows had a rectal temperature >38.5°C ($p$ = 0.02; Fig.3.1.2b).

This is in agreement with the findings of Schmidt et al. (2013) who found that eye and ear base temperatures were good predictors of rectal temperature in febrile sows, and concluded that these measures be used to complement rectal temperature in veterinary investigations on farm. For our observations we used the maximum temperature over the location of interest, extracted using the Matlab program, and other authors have previously noted that maximum temperature of the location of interest may be a better predictor of internal body temperature than average temperature of an area (Soerensen and Pedersen, 2015; Rosengart et al., 2021).

Previous studies have found a good correlation between rectal temperature and udder temperature (Traulsen et al., 2010; Rosengart et al., 2022); however, that was not the case in our experiment. This may be impacted by the fact that the previous authors have measured whole udder temperatures rather than pointer temperatures and have included larger locations of interest in their analysis (i.e., the whole udder or the first six teat pairs).

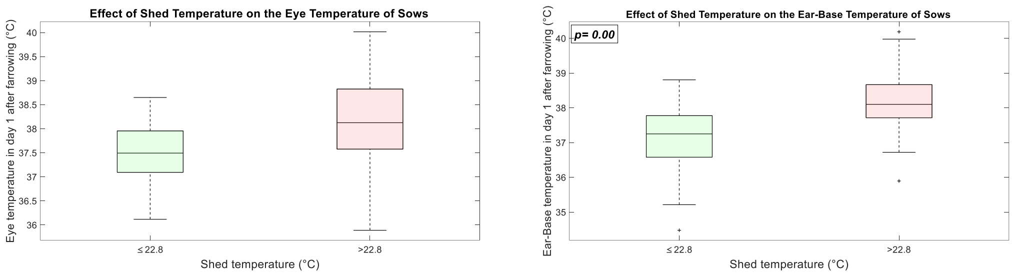



(a) (b)

**Fig. 3.1.2:** Skin temperature of sows with a rectal temperature of ≤38.5°C (*n* = 67) in comparison to sows with a rectal temperature >38.5°C (*n* = 51). a) Eye and b) ear base temperature.

*Relationships between shed and skin temperatures*

The effect that shed temperature has on the skin temperature of sows was also analysed, and our results suggest that high temperatures in the shed are also reflected in the eye and ear base temperature of sows. It was observed that average eye temperature was 37.5 ± 0.60°C when the temperature of the shed was ≤22.8°C, while average eye temperature was 38.2 ± 0.84°C when the temperature of the shed was >22.8°C ($p < 0.001$; Fig. 3.1.3a). Moreover, the average ear base temperature was 37.1 ± 0.90°C when the temperature of the shed was ≤22.8°C, and 38.2 ± 0.85°C when the temperature of the shed was >22.8 °C ($p < 0.001$; Fig. 3.1.3b).



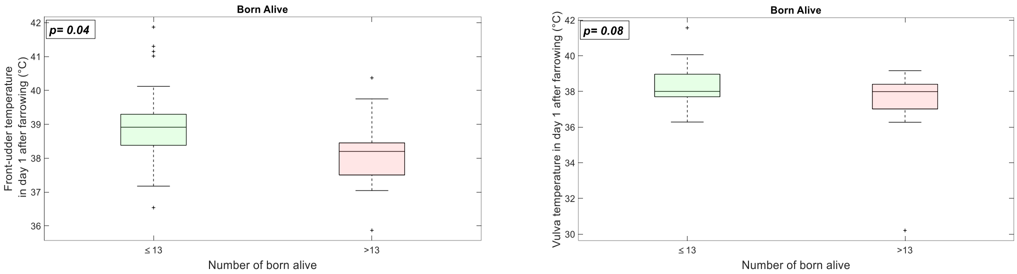

(a) (b)

**Fig. 3.1.3:** Difference in the skin temperature of sows when the temperature of the shed was ≤22.8°C (*n* = 67) in comparison to when the temperature of the shed was >22.8°C (*n* = 51). a) Eye and b) ear base temperature.

## b) Relationships between thermal temperatures and sow reproductive output

*Relationship between the number of piglets born alive and the skin temperature of sows*

The skin temperature of sows was also analysed to identify the differences between the group of sows that had ≤13 piglets born alive (*n* = 28) and the group of sows that had >13 piglets born alive (*n* = 13). The most relevant differences were observed from the temperatures measured at the anterior teats and the skin temperature obtained from the vulva on day 1 of lactation. The skin temperature of the anterior teats was significantly higher ($p$ = 0.04) in the group of sows that had ≤13 piglets born alive (39.1 ± 1.24°C) than in the group of sows that had >13 piglets born alive (38.1 ± 1.18°C; Fig. 3.1.4a). In addition, skin temperature around the vulva on day 1 of lactation tended to be higher ($p$ = 0.08) in sows that had ≤13 piglets born alive (38.4 ± 1.17°C) than in the group of sows that had >13 piglets born alive (37.3 ± 2.37°C; Fig. 3.1.4b).

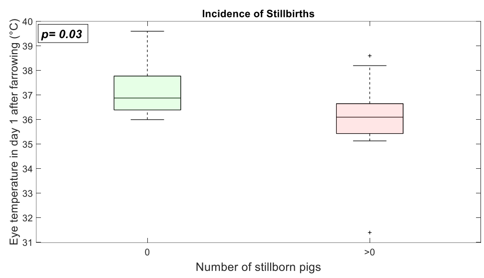



**(a)** **(b)**

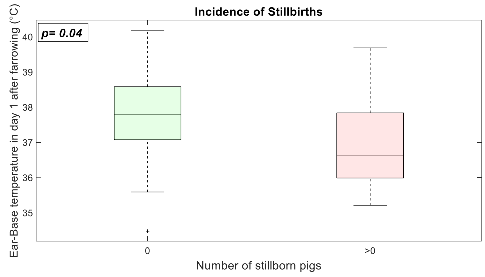
**Fig. 3.1.4:** Differences in skin temperatures on day 1 of lactation between sows that had ≤13 piglets born alive and sows that had >13 piglets born alive. a) Anterior teats and b) vulva temperature.

Similarly, the skin temperature of sows was analysed to identify the differences between the group of sows that did not have any stillborn piglets ($n$ = 24) and the group of sows that farrowed at least one stillborn piglet ($n$ = 17). Overall, the skin temperatures of the eye and the ear base were higher in the sows that did not have stillborn piglets than those that had at least one (Fig. 3.1.5). On day 1 of lactation, sows that did not have any stillborn piglets had a significantly higher eye temperature (38.2 ± 0.89°C) than those that had farrowed at least one stillborn piglet (37.5 ± 1.06°C; $p$ = 0.03; Fig. 3.1.5a). However, there was no difference in Ear base between these groups of sows on day 9 of lactation (37.9 ± 0.58°C and 37.5 ± 0.65°C, respectively; $p$ > 0.05; Fig. 3.1.5c).

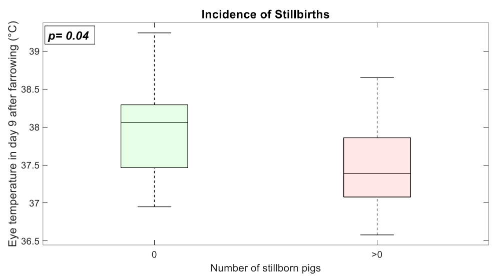
On day 1 of lactation, sows that had no stillborn piglets had a significantly higher ($p$ = 0.04) average ear base temperature (38.0 ± 0.64°C) compared to those that had at least one stillborn piglet (37.6 ± 0.85°C; Fig. 3.1.5b). However, the difference in ear base temperature between the two sow groups was not significant on day 9 of lactation ($p$ = 0.14; Fig. 3.1.5d).



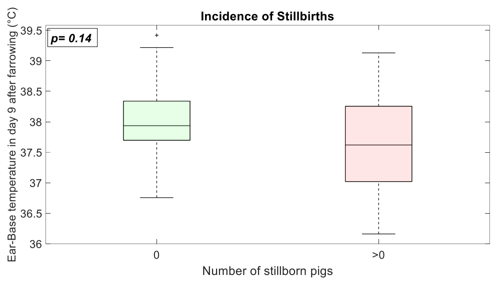

(a)




(b)




(c)




(d)

**Fig. 3.1.5:** Differences in skin temperatures between sows that farrowed no stillborn piglets (0) and the sows that farrowed at least 1 stillborn piglet (>0). a) Eye on day 1 of lactation; b) Ear base on day 1 of lactation; c) Eye on day 9 of lactation; and d) Ear base on day 9 of lactation.

*Relationships with piglet birth weight (post-foster)*

The temperature obtained from the posterior teats on day 1 of lactation was significantly lower ($p < 0.001$) in sows that had lighter pigs at birth (≤1.5 kg on average; $n$ = 17; 37.9 ± 0.55˚C) than in sows that had heavier pigs at birth (>1.50 kg on average; $n$ = 16; 38.8 ± 0.69˚C; Fig. 3.1.6). However, this did not consider whether piglets had been fostered on from another sow or off to a foster sow. Fig. 3.1.7 shows the differences between sow groupings when average piglet weight at birth was split into quartiles.

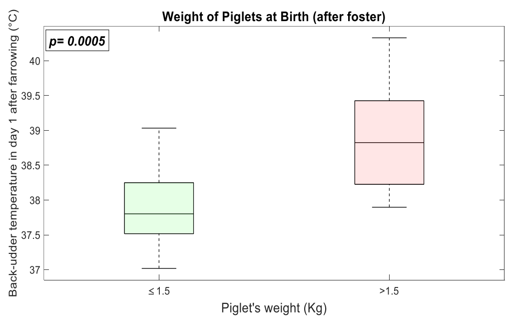



**Fig. 3.1.6:** Differences in posterior teat skin temperature on day 1 of lactation between the groups of sows that had piglets that weighed ≤1.50 kg ($n$ = 17) or >1.50 kg ($n$ = 16; on average) at birth.


**Fig. 3.1.7:** Differences in posterior teat skin temperature on day 1 of lactation between the groups of sows that had piglets that weighed ≤1.37 kg ($n$ = 9), 1.38-1.52 kg ($n$ = 8), 1.53-1.74 kg ($n$ = 8), or >1.74 kg ($n$ = *8*; on average) at birth.

*Relationships with piglet weight in late lactation*
Similar analyses were performed to consider piglets' weight before weaning (day 16 of lactation), which suggested skin temperatures (specifically ear base and vulva) obtained early in lactation (day 1) are higher ($p < 0.10$) in sows that weaned piglets with lower average weaning weights (≤4.8 kg; $n$ = 17) than in sows that weaned piglets with higher average weaning weights (>4.8 kg; $n$ = 16). However, temperatures (specifically of the posterior teats and eye) obtained in later lactation (day 16) were lower ($p < 0.10$) in sows that weaned lighter piglets compared to sows that weaned heavier piglets (Fig. 3.1.8).

Ear base temperature on day 1 of lactation was significantly higher ($p = 0.009$) in sows weaning lighter piglets (37.6 ± 0.88°C) than sows weaning heavier piglets (36.5 ± 1.33°C; Fig. 3.1.8a). Vulva temperature on day 1 of lactation tended ($p = 0.05$) to be higher in sows weaning lighter piglets (38.2 ± 0.81°C) than sows weaning heavier piglets (36.9 ± 2.21°C; Fig. 3.1.8b).

On the other hand, it was observed that posterior teat temperature on day 16 of lactation was significantly ($p = 0.009$) lower in sows that weaned piglets with lower average weights (37.5 ± 0.98°C) than in sows that weaned piglets with higher average weights (38.4 ± 0.76°C; Fig. 3.1.8c). Furthermore, eye temperature tended ($p = 0.06$) to be higher in sows weaning lighter piglets (38.1 ± 0.63°C) than sows weaning heavier piglets (37.6 ± 0.86°C; Fig. 3.1.8d).

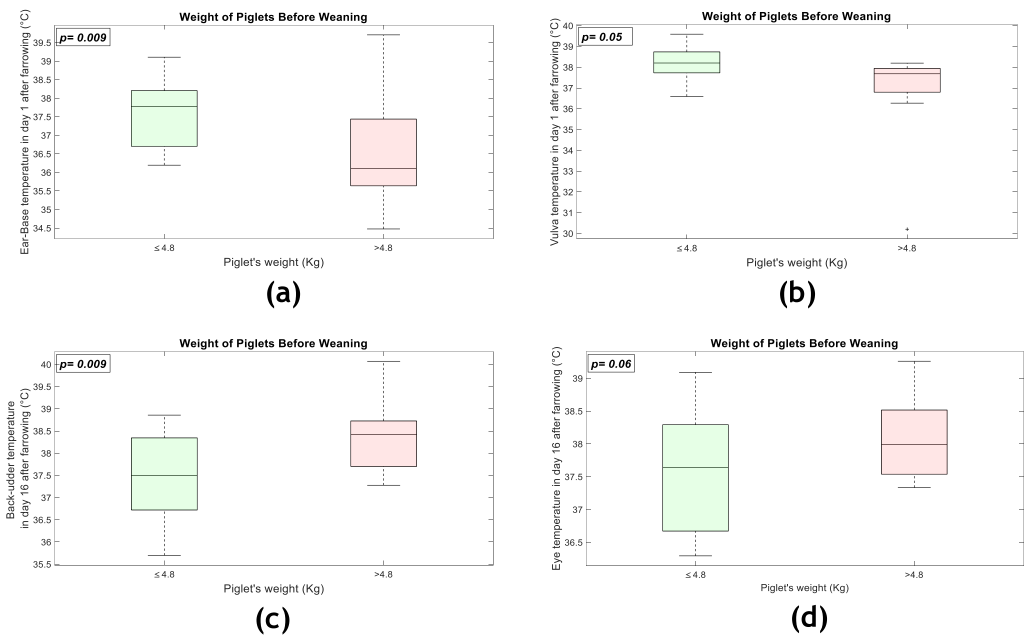



**Fig. 3.1.8:** Differences in skin temperatures between the groups of sows that had piglets that weighed ≤4.80 kg or >4.80 kg before weaning (on average). a) Ear base, b) vulva, c) posterior teat and d) eye temperatures.

*Relationship between sow body temperatures and heat lamp proximity*
For a number of sows, it was observed that the heat lamp over the creep area was covering an area of the sow's body. The sows' rectal temperature recorded when an area of their body was covered by the heat lamp ($n$ = 54) was compared with the rectal temperatures recorded when sows were not reached by the heat lamp ($n$ = 58).

It was observed that the skin temperature of the area covered by the light (heat) of the heat lamp (selected by hand and extracted by Matlab) was 1–4°C higher than the skin temperature of the surrounding area. Furthermore, the rectal temperature of sows was higher ($p < 0.05$) when an area of their body was covered by the heat lamp than when sows were not reached by the heat lamp, and this effect was consistent over different shed temperatures (Table 3.1.2).

**Table 3.1.2:** Descriptive statistics of sows' rectal temperature with no threshold of shed temperature ($n$ = 112), shed temperature ≤ 23°C ($n$ = 58), and shed temperature > 23°C ($n$ = 54). Statistics are split by the coverage of heat lamps on sows (when sows were not reached by the heat lamp compared to when an area of their body was covered by the heat lamp; adapted from Jorquera-Chavez et al. (2021a).

| | Not reached by heat lamp | | | Reached by heat lamp | | | |
|---|---|---|---|---|---|---|---|
| Shed temperature threshold | n | Mean (°C) | Range (°C) | n | Mean (°C) | Range (°C) | *p* value |
| No threshold | 58 | $38.4^{a}$ | 37.2-39.1 | 54 | $38.7^{b}$ | 37.8-40.8 | <0.001 |
| Shed temp. ≤ 23°C | 29 | $38.3^{a}$ | 37.2-39.1 | 29 | $38.6^{b}$ | 37.8-40.1 | 0.029 |
| Shed temp. > 23°C | 29 | $38.4^{a}$ | 37.2-39.1 | 25 | $38.9^{b}$ | 38.4-40.8 | <0.001 |

[ab]Means within a row with different superscripts differ significantly ($p < 0.05$).

These results suggest that heat lamps impact skin and rectal temperature of sows when the light from the lamp covers an area of their body, which is often the case in commercial production. This could have a negative effect on sow performance, especially in conditions of heat stress during hot summer periods. Further studies are required to investigate alternative heat source types and positions while aiming to meet both piglets' and sows' thermal requirements, as this would assist in reducing heat stress in lactating sows.

## c) Relationships between thermal temperatures and health status of sows

*Relationships with sow medication rates in lactation*

Three sows were treated during the course of lactation in the current experiment. These sows were given an intramuscular injection of penicillin (Amoxycillin) as their piglets showed signs of scours within the first 3 days of life. Skin temperature in some of the locations measured on day 1 of lactation showed some relevant trends when comparing it between the group of sows that were never treated during the lactation period ($n$ = 38) vs. the groups of sows that was treated at some point of the lactation ($n$ = 3). For instance, the skin temperature of the whole udder measured on day 1 of lactation showed a significant difference ($p$ = 0.04) between the group of sows that were treated (39.3 ± 0.25°C) and the group that were not (38.4 ± 0.73°C; Fig. 3.1.10). Unfortunately, the reason for treatment was not recorded. In addition, although the difference in eye temperature was not significant between these two groups ($p$ = 0.39), it was observed that the skin temperature around the eye area on day 1 after farrowing tended to be higher in sows that received treatment (38.4 ± 1.43°C) than sows that those that did not receive any treatment during lactation (37.9 ± 0.98; Fig. 3.1.11).

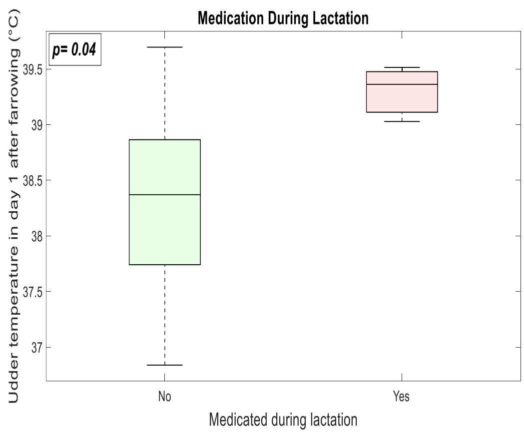



**Fig. 3.1.10:** Difference in udder skin temperature on day 1 of lactation between sows that did not receive treatment during the lactation ("No") and sows that did receive treatment during the lactation ("Yes").

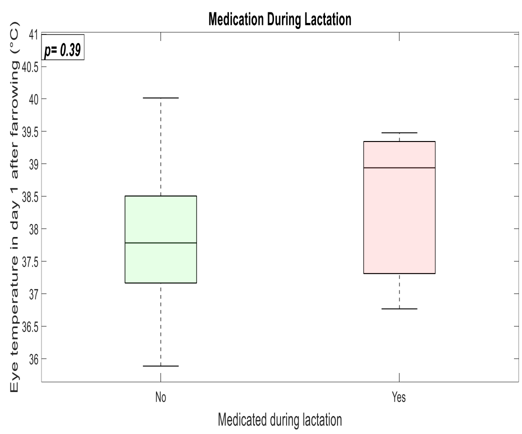



**Fig. 3.1.11:** Difference in eye temperature on day 1 of lactation between sows that did not receive treatment during the lactation ("No") and sows that did receive treatment during the lactation ("Yes").

*Relationships with incidence of shoulder sores in sows*

Although there was not a high incidence of shoulder sores in the participating sows (there were not severe cases observed), there was a group of sows that presented signs of shoulder sore development in lactation (Score 1), most of which occurred on day 16 of lactation ($n$ = 7). When evaluating the differences in skin temperatures between the sows that received Score 1 on day 16 and the sows that showed no sign of shoulder sores on day 16 (Score 0; $n$ = 33), it was observed that sows with a developing shoulder sore had numerically higher skin temperatures than the sows that had no evidence of shoulder sore development (eye temperature 37.8 ± 0.79 and 37.7 ± 0.24°C, respectively; ear base temperature 37.5 ± 0.99 and 36.9 ± 0.33°C, respectively). Furthermore, significant differences between these two groups were identified when assessing eye temperature (39.5 ± 0.58°C and 37.8 ± 0.92°C, respectively), ear base temperature (39.1 ± 1.05°C and 37.3 ± 1.34°C, respectively), and shoulder temperature (38.4 ± 1.42°C and 35.9 ± 1.61°C, respectively) at day 1 of lactation (all $p < 0.05$; Fig. 3.1.12).

Overall, from the results of Experiment 1, it seems that the base of the ear, shoulder and posterior teat skin temperatures are most informative in relation to sow performance in a commercial setting. Therefore, these areas were selected for further investigation in Experiment 2.

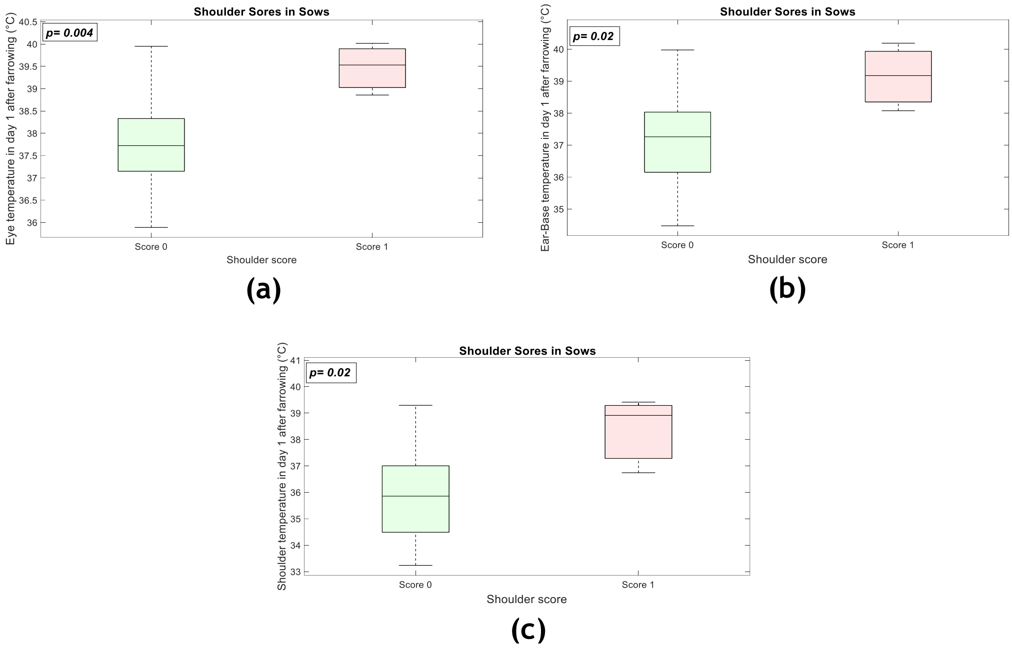



**Fig. 3.1.12:** Difference in skin temperature on day 1 of lactation between sows that did not present shoulder sores ("Score 0") and sows that presented with shoulder sores during the experimental period ("Score 1"). (a) Eye, (b) ear base and (c) shoulder temperature.

## d) Relationships between thermal temperatures and piglet vitality and survival

*Correlation between surface and rectal temperatures*

Ear base pointer and extracted temperatures showed low correlations with rectal temperature at 0 h and 24 h (Table 3.1.3). Ear tip pointer temperature showed a moderate correlation to rectal temperature at 0 h ($R^2$ = 0.13, $p$ = 0.13) but was not well correlated at 24 h ($R^2$ < 0.001; $p$ = 0.68). Extracted values for ear tip were not well correlated with rectal temperature at either timepoint ($R^2$ = 0.04, $p$ = 0.21 and $R^2$ < 0.001, $p$ = 0.73, respectively). Eye pointer temperature showed a medium correlation with rectal temperature at 0 h ($R^2$ = 0.25; $p$ < 0.001) but not at 24 h (R = 0.02; $p$ = 0.29; Table 3.1.3). Eye extracted values were not well correlated with rectal temperature at 0 h ($R^2$ = 0.22; $p$ = 0.003) or 24 h (R = 0.04; $p$ = 0.10).

**Table 3.1.3:** Pearson's correlation coefficients (r; 95% confidence intervals in parentheses) between rectal temperature and surface temperature locations for pointer and extracted temperatures at 0 h (birth) and 24 h in 109 piglets. N = number of observations.

| | | **Time (relative to birth)** | |
|---|---|---|---|
| | | **0 h** | **24 h** |
| | **N** | 48 | 61 |
| **Ear base** | **Pointer** | 0.38 (0.11 – 0.60) | 0.22 (-0.03 – 0.45) |
| | **Extracted** | 0.31 (0.03 – 0.55) | 0.30 (0.05 – 0.51) |
| **Ear tip** | **Pointer** | 0.36 (-0.11 – 0.70) | -0.07 (-0.39 – 0.26) |
| | **Extracted** | 0.19 (-0.10 – 0.45) | 0.05 (-0.21 – 0.29) |
| **Eye** | **Pointer** | 0.50 (0.25 – 0.69) | 0.14 (-0.12 – 0.38) |
| | **Extracted** | 0.42 (0.15 – 0.53) | 0.21 (-0.04 – 0.44) |

*Comparison between pointer and extracted skin temperatures*

Ear base and eye temperatures showed a high correlation between pointer and extracted values ($R^2$ = 0.73 and 0.82, respectively; $p < 0.001$; Fig. 3.1.13), while the ear tip showed a moderate correlation between pointer and extracted values ($R^2$ = 0.52; $p < 0.001$).

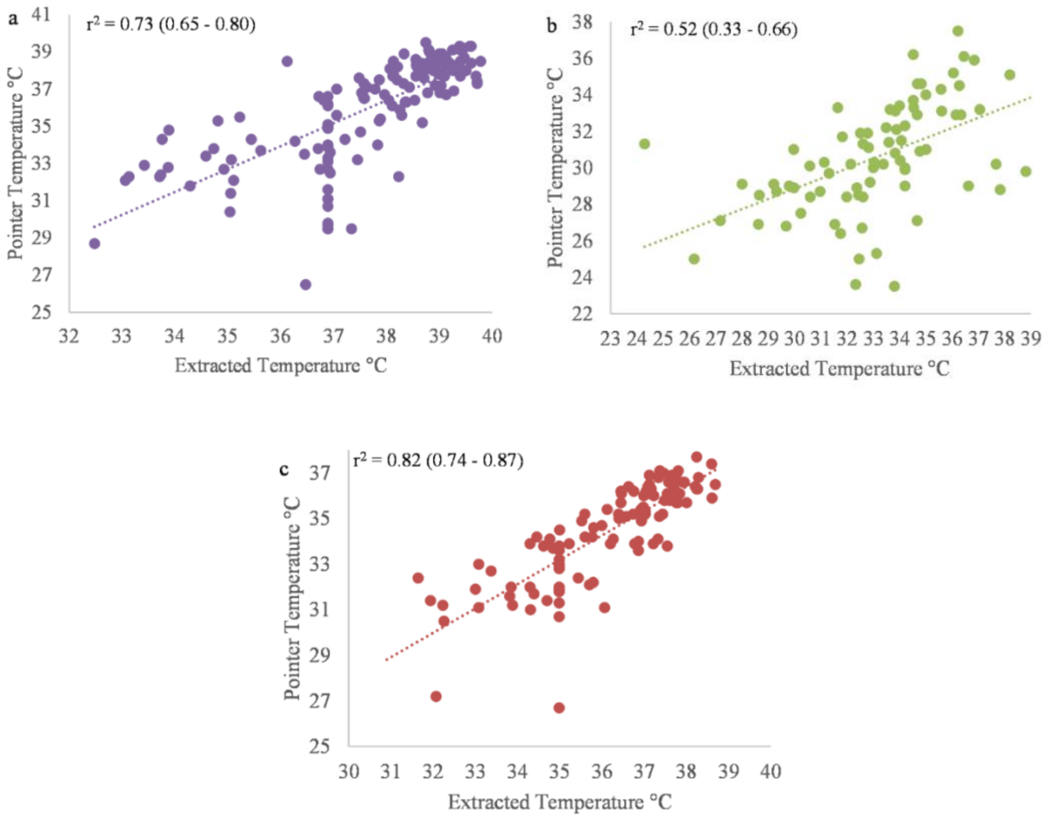



**Fig. 3.1.13:** Coefficient of determination ($R^2$) and respective 95% confidence intervals for the relationship between extracted (x axis) and pointer (y axis) temperatures at the (a) ear base, (b) ear tip and (c) eye in 109 piglets (Tucker, 2022).

*Factors affecting thermal surface temperature in piglets*
Colostrum intakes over the first 24 h of life averaged 290 g (± 38.5 SEM) for piglets selected for this analysis. Ear base temperatures (extracted or pointer) were not significantly impacted by colostrum intake ($p \geq 0.10$) and were higher ($p < 0.001$) at 24 h than at 0 h (Table 3.1.4). Pointer eye temperature was not significantly impacted by colostrum intake ($p = 0.48$) but extracted temperature was significantly higher in those piglets consuming ≥ 200 g of colostrum ($p = 0.01$; Table 3.1.4). Both temperatures were lower at birth than at 24 h ($p < 0.001$). Rectal temperature did not differ significantly between the two colostrum intake groups ($p = 0.29$) but tended ($p = 0.08$) to be higher at 24 h than at birth (data not shown).

**Table 3.1.4:** Least square mean ± SEM for extracted and pointer thermal temperature values taken at the base of the ear and eye of 109 piglets between birth (0 h) and 24 h after birth. Piglets were categorised as having consumed less or more than 200 g of colostrum in the first 24 h. N = number of piglets per group.

| | | Ear base (°C) | | |
|---|---|---|---|---|
| | | **N** | **Extracted** | **Pointer** |
| **Time** | **0 h** | 48 | 36.4 ± 0.41 * | 34.4 ± 0.58 * |
| | **24 h** | 61 | 38.5 ± 0.38 | 37.6 ± 0.52 |
| **Colostrum** | **< 200 g** | 38 | 37.2 ± 0.42 | 35.9 ± 0.59 |
| | **≥ 200 g** | 71 | 37.7 ± 0.37 | 36.1 ± 0.51 |

| | | Eye (°C) | | |
|---|---|---|---|---|
| | | N | **Extracted** | **Pointer** |
| **Time** | **0 h** | 48 | 34.7 ± 0.24 * | 32.9 ± 0.30 * |
| | **24 h** | 61 | 37.4 ± 0.21 | 35.8 ± 0.27 |
| **Colostrum** | **< 200 g** | 38 | 35.6 ± 0.26 * | 34.3 ± 0.32 |
| | **≥ 200 g** | 71 | 36.4 ± 0.20 | 34.5 ± 0.24 |

*Indicates $p < 0.001$ between categories within method and variable.

*Relationships between piglet temperatures, vitality and immunocrit ratio*
Immunocrit ratio was not highly correlated with birth weight ($R^2 = 0.02$), or rectal temperature at birth ($R^2 = 0.05$) or at 24 h ($R^2 = 0.01$). Similarly, immunocrit ratio was not highly correlated with ear base temperature ($R^2 = 0.01$) or ear tip temperature ($R^2 = 0.04$), both measured with the pointer. Likewise, there was no correlation between colostrum intake and immunocrit ($R^2 < 0.001$).

Given the results from previous studies (Vallet et al., 2013), it would be expected that these correlations would be higher than observed in the current study. It should be noted that immunocrit ratios measured in our study were higher than that of Vallet et al. (2013) and it is possible that these samples were not spun for long enough to allow the precipitate to settle fully at the bottom on the tube. Nonetheless, from our results it seems that immunocrit ratio was not correlated with other measures of piglet vitality at birth mentioned above. There were no other significant differences between any other temperature and performance variables.

## e) Comparisons between thermal camera technologies

The FLIR E8 camera was considered the best camera to be used on farm as it was easy to use, battery operated, has long-life battery, acceptable memory capacity and a built-in screen. Additionally, based on the observations from Experiment 1, the base of the ear, shoulder and posterior teats were chosen as the areas to be used in Experiment 2 to measure skin temperature of sows, as they were easiest to record and would therefore be more commercially applicable.

Additionally, the posterior teats of the udder were chosen as another site for skin temperature measurement to be used in Experiment 2 as this is where mastitis is more likely to occur (Bostedt et al., 1998; Baer and Bilkei, 2005; Kemper and Gerjets, 2009), and the teats that last born piglets are usually given to suckle when teat order is established. It is also easier to obtain thermal images of this teat as the operator does not have to get into the pen to take the image. Shoulder skin temperature was also chosen to be used in Experiment 2 to further explore the relationship between shoulder temperatures and shoulder sore formation. These conclusions are in corroboration with the findings of Soerensen et al. (2014).

A standard operating procedure (SOP) was then developed for measurement of the ear base and eye temperatures using the FLIR E8 camera (Appendix 1). This SOP was used to obtain thermal images for Experiment 2 and experiments within our related APRIL projects (6A-101 and 6A-102).

## 3.2 Experiment 2: Commercial evaluation of the FLIR E8 camera

Thermal images from a total of 264 sows were used in the analysis for Experiment 2 (*n* = 6 sows were removed for commercial reasons before the end of the experimental period). Average performance data of these sows are presented in Table 3.2.1.

**Table 3.2.1:** Descriptive statistics for performance data of sows involved in Experiment 2.

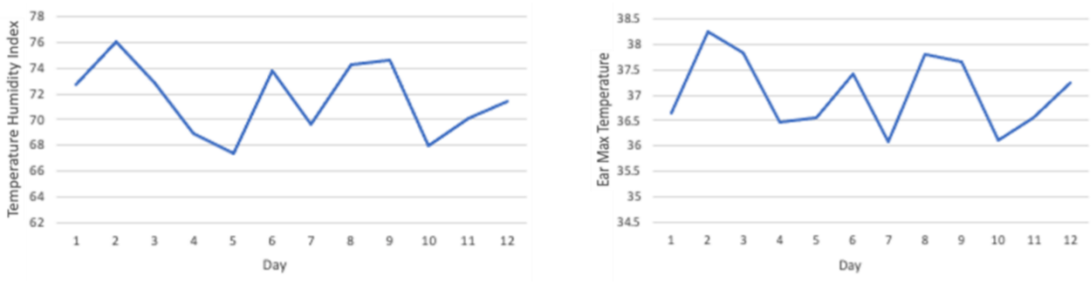
| | Statistic | | | | |
|---|---|---|---|---|---|
| Variable | n | Min | Max | Mean | SE |
| ***Sows*** | | | | | |
| Parity at farrowing | 264 | 3 | 7 | 3.7 | 0.08 |
| Sow weight at entry (kg) | 264 | 231 | 377 | 290.9 | 1.65 |
| Sow P2 at entry (mm) | 224 | 10.0 | 41.4 | 21.4 | 0.34 |
| Gestation length (d) | 263 | 111 | 125* | 116.9 | 0.13 |
| Entry to farrowing (d) | 263 | 0 | 15 | 7.7 | 0.17 |
| Born alive | 263 | 0 | 22 | 9.9 | 0.34 |
| Stillborn | 263 | 0 | 14* | 1.7 | 0.13 |
| Total born | 263 | 1 | 25 | 13.3 | 0.27 |
| Litter weight post-foster (kg) | 229 | 6.5 | 26.6 | 15.9 | 0.26 |
| Litter number post-foster | 263 | 0* | 17 | 9.5 | 0.25 |
| Ave piglet weight post-foster (kg) | 229 | 0.98 | 2.50 | 1.57 | 0.056 |
| Litter weight wean (kg) | 186 | 16.1 | 139.2 | 83.0 | 1.71 |
| Litter number at wean | 192 | 4 | 14 | 8.9 | 0.16 |
| Ave piglet weight wean (kg) | 192 | 4.03 | 14.26 | 9.43 | 0.132 |
| Sow ADFI in lactation (kg/d) | 228 | 6.5 | 12.0 | 9.8 | 0.07 |
| Sow weight at weaning (mm) | 227 | 197 | 345 | 275.7 | 1.97 |
| Sow P2 at weaning (mm) | 222 | 10.0 | 42.0 | 20.3 | 0.30 |
| Weaning age (d) | 228 | 21 | 36 | 29.1 | 0.23 |

ADFI = average daily feed intake; P2 = backfat thickness at the P2 site. *Sows impacted by Japanese Encephalitis Virus (JEV) and hence exhibited a prolonged gestation length.

### a) Relationships between different temperature measurements

Ambient temperatures recorded with the temperature logger in the first replicate were compared to the skin temperatures taken at each of the three locations of interest in the first replicate. Ear base temperature was highly correlated with ambient shed temperature and this relationship was significant ($R^2 = 0.32$; $p = 0.03$). Correlations were low between ambient temperature and shoulder skin temperature ($R^2 = 0.10$; $p = 0.26$) and udder temperature ($R^2 < 0.10$; $p = 0.90$).

A highly significant correlation ($R^2 = 0.77$; $p < 0.001$) was observed between thermal humidity index (THI; Bohmanova et al., 2007) and ear base temperature during this period. The relationship between these two variables can be observed in Fig. 3.2.1.




**(a)** **(b)**

**Fig. 3.2.1:** Visualisation of (a) average thermal humidity index (THI) and (b) average ear base temperatures (adapted from Lewis, 2022).

Between the three areas where skin temperature was measured, ear base and shoulder showed the highest significant correlation ($R^2 = 0.80$; $p < 0.001$; Fig. 3.2.2).

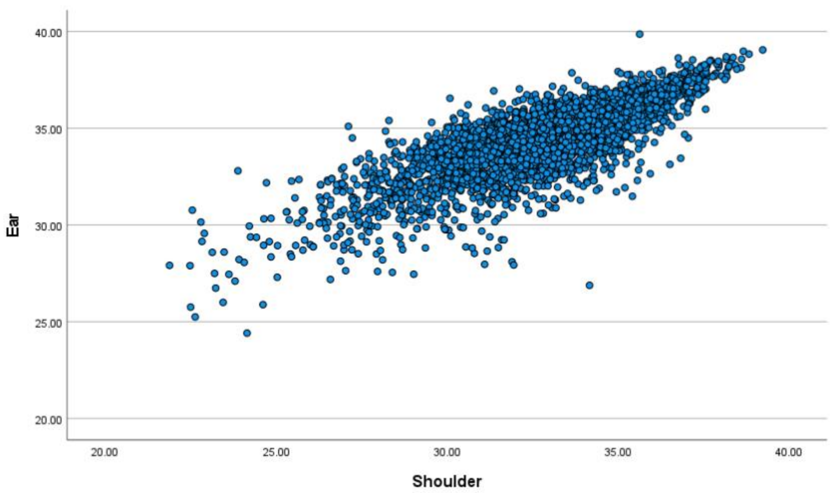



**Fig. 3.2.2:** Relationship between shoulder (x axis) and ear base (y axis) skin temperature (°C).

Ear base and shoulder temperature were significantly correlated with udder temperature ($R^2$ = 0.49 and 0.52, respectively; $p < 0.001$; Fig. 3.2.3 and 3.2.4). Udder temperature seemed to be better correlated with ear base and shoulder temperature at temperatures exceeding 35°C (Fig. 3.2.3 and 3.2.4).

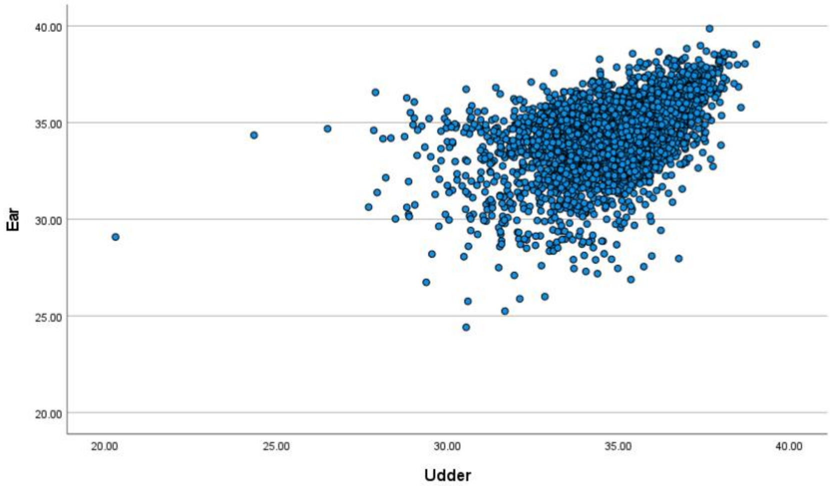



**Fig. 3.2.3:** Relationship between ear base (y axis) and udder (x axis) skin temperature (°C).

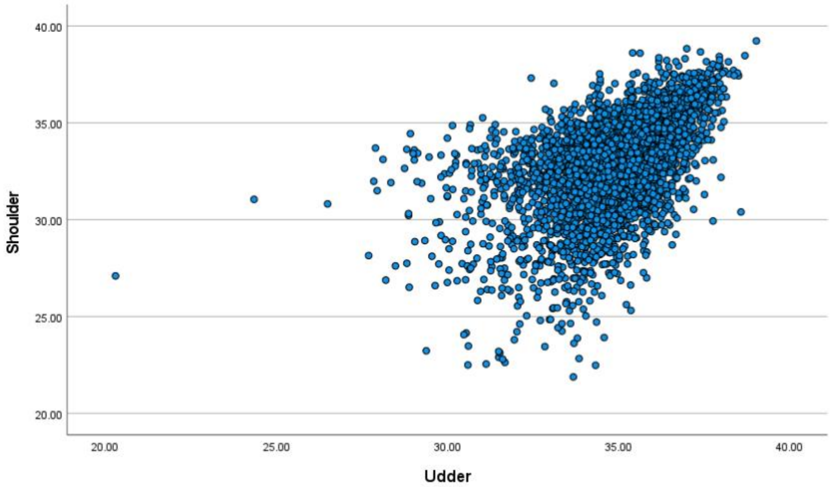



**Fig. 3.2.4:** Relationship between udder (x axis) and shoulder (y axis) skin temperature (°C).

## b) Relationships between thermal temperatures and sow reproductive output

The relationship between ADFI of sows and their ear base temperatures was analysed for the first replicate of sows, which appeared to be slightly correlated ($R^2$ = 0.14; $p$ = 0.02; Fig. 3.2.5).

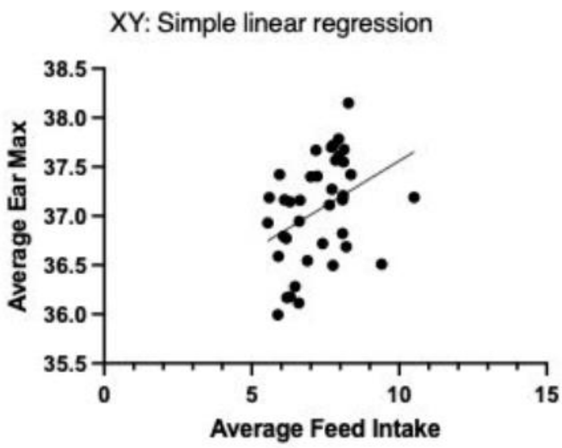



**Fig. 3.2.5:** Relationship between sow average daily feed intake in lactation (x axis) and ear base temperature (y axis) during the first replicate (adapted from Lewis, 2022).

Ear base temperature did not differ between sows with ≤13 piglets BA or >13 piglet BA overall or at any timepoint ($p \geq 0.10$). However, there tended to be an interaction between BA grouping and timepoint for shoulder temperature ($p$ = 0.066). In the week leading up to farrowing ($p$ = 0.041) and the week of farrowing ($p$ = 0.031), shoulder temperature was significantly higher in those sows that had ≥13 BA (Fig. 3.2.6). One possible explanation for this is that sows with higher litter sizes of >13 piglets may exhibit more nest building behaviour in this period than those with ≤13 (Pedersen et al., 2006), hence having more postural changes around farrowing and allowing for less friction between the shoulder and the farrowing crate (Westin and Rydberg, 2010).

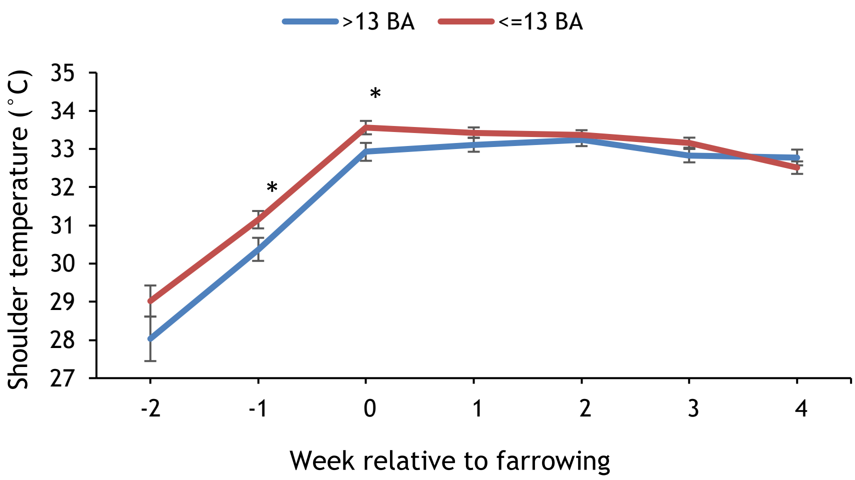



**Fig. 3.2.6:** Average shoulder temperature by week relative to farrowing for sows with >13 piglets born alive (BA; red line) vs. those with ≤13 piglets BA (blue line). BA grouping $p$ < 0.11, Week $p$ < 0.001, BA grouping*Week $p$ = 0.066. *Indicates a significant ($p$ < 0.05) difference between BA grouping at that timepoint.

Furthermore, there was a significant interaction between BA grouping and timepoint for udder temperature ($p$ = 0.027). However, no significant pairwise interactions between BA groupings at individual timepoints were found (all $p \geq 0.10$; Fig. 3.2.7).

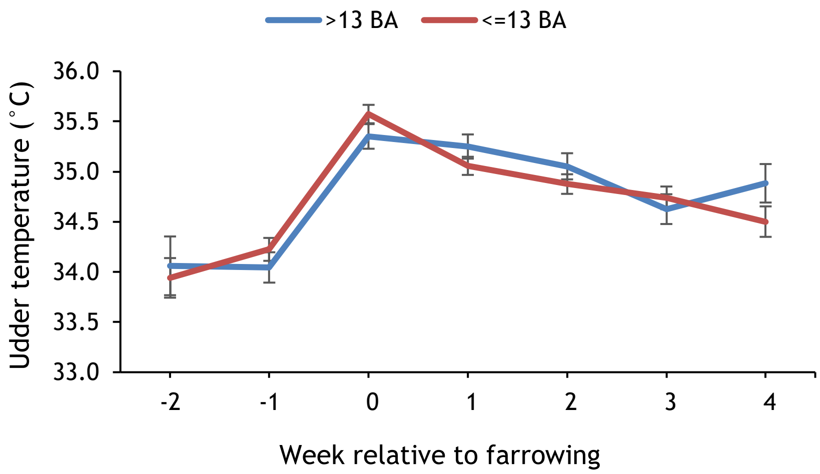



**Fig. 3.2.7:** Average udder temperature by week relative to farrowing for sows with >13 piglets born alive (BA; red line) vs. those with ≤13 piglets BA (blue line). BA grouping $p < 0.11$, Week $p < 0.001$, BA grouping*Week $p = 0.066$.

There were no differences in ear base, shoulder or udder temperatures at any timepoint between sows with at least 1 SB piglet and sows with no SB piglets. Furthermore, there were no significant relationships between any skin temperatures and sows that had an average piglet birth weight (post-foster) >1.5 kg than those with an average piglet birth weight of ≤1.5 kg. Similarly, there were no significant differences at any timepoint between sows with an average piglet weaning weight of ≥10 kg or those with an average piglet weaning weight of <10 kg (all $p \geq 0.10$; data not shown).

## c) Relationships between thermal temperatures and health status

There was no significant difference between ear base, shoulder or udder temperatures of sows that were medicated ($n = 17$) vs. those that were not at any week timepoint studied (main and interaction $p \geq 0.05$; data not shown). There were no significant differences in skin temperatures in sows that exhibited any udder abnormalities, such as swelling and inflammation ($n = 84$; i.e., diagnosed as having mastitis) and those that did not ($p \geq 0.10$; data not shown). The apparent mastitis incidence recorded in this study was quite higher than expected for this commercial farm, and this may have been due to operator error. Further studies should use somatic cell counts or other pathological methods to formerly diagnose mastitis and investigate the links between skin temperature and mastitis incidence.

On average, sows that developed a shoulder sore (score 1; $n = 41$) had higher overall shoulder temperatures (32.4 ± 0.28°C) than those that didn't develop shoulder sores (32.1 ± 0.14°C); however, this was not significant ($p = 0.27$) and no timepoint was more informative than any of the others, shown by a non-significant interaction between shoulder sore development and timepoint ($p = 0.39$). A small difference such as this over the course of a whole lactation period would be difficult to pick up in a commercial setting - some timepoints may be more informative than others; however, we may have lacked the sample size to detect any differences. When a *post hoc* comparison was carried out on shoulder temperature between sows that developed shoulder sores and those that didn't at all timepoints, the only significant difference was found in the fourth week of lactation (33.3 ± 0.26 vs. 32.4 ± 0.14°C, respectively; $p = 0.009$), which would be unhelpful in early detection of shoulder sores in commercial production.

Due to the outbreak of JEV that occurred during the experiment, a number of sows required assistance at farrowing as piglets had died *in utero* and farrowing was not initiated naturally. Aside from these pigs, no other sows in the study required assistance farrowing so relationships between skin temperatures in sows requiring farrowing assistance could not be studied. However, interestingly, pigs that were identified as suffering from symptoms of JEV (such as piglets shaking and non-viable when born, no piglets born alive, failure to farrow on or near their expected due date, and/or increased farrowing duration) had significantly higher ear ($p = 0.002$; Fig. 3.2.8), shoulder ($p < 0.001$; Fig. 3.2.9) and udder temperatures ($p = 0.006$; Fig. 3.2.10) than those that didn't show clinical signs of JEV infection. Ear and shoulder temperatures were significantly higher in the week preceding farrowing for sows that experienced symptoms of JEV infection compared to those that didn't ($p < 0.05$). This could be an important finding, as body temperatures could be monitored easily using the E8 camera to confirm JEV before farrowing occurs and identify sows at risk in the event of a known outbreak. It is important to note that gestation length was higher in sows identified as having JEV (118 ± 3.0 d) compared to those that didn't (117 ± 1.6 d), as weeks relative to farrowing would be influenced by this. Expected due date was not recorded for all sows in the current study; however, it would be interesting to see whether the same effect was seen in the weeks leading up to the expected farrowing date.

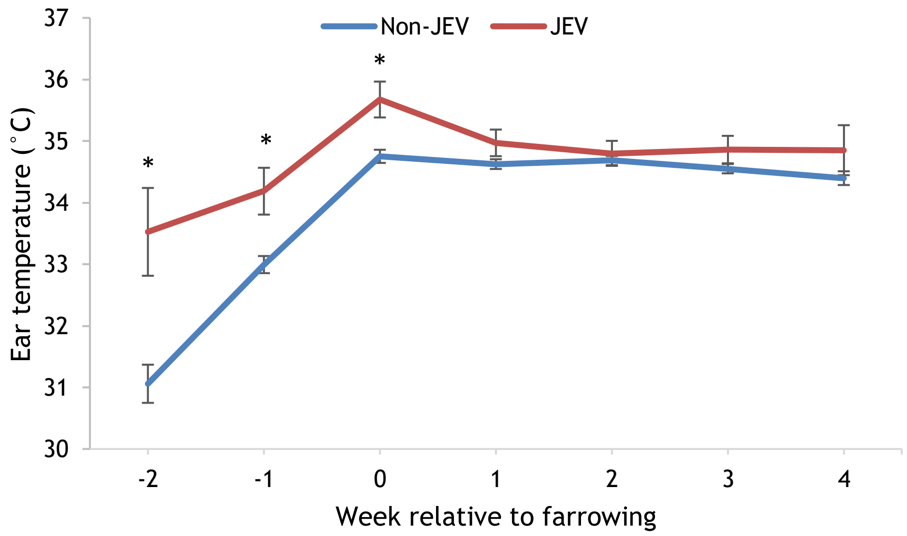



**Fig. 3.2.8:** Average ear base temperature by week relative to farrowing for sows suffering clinical symptoms of Japanese Encephalitis Virus (JEV; red line) vs. those not showing signs (blue line). JEV status $p = 0.002$, Week $p < 0.001$, JEV*Week $p = 0.018$. *Indicates a significant ($p < 0.05$) difference between JEV status at that timepoint.

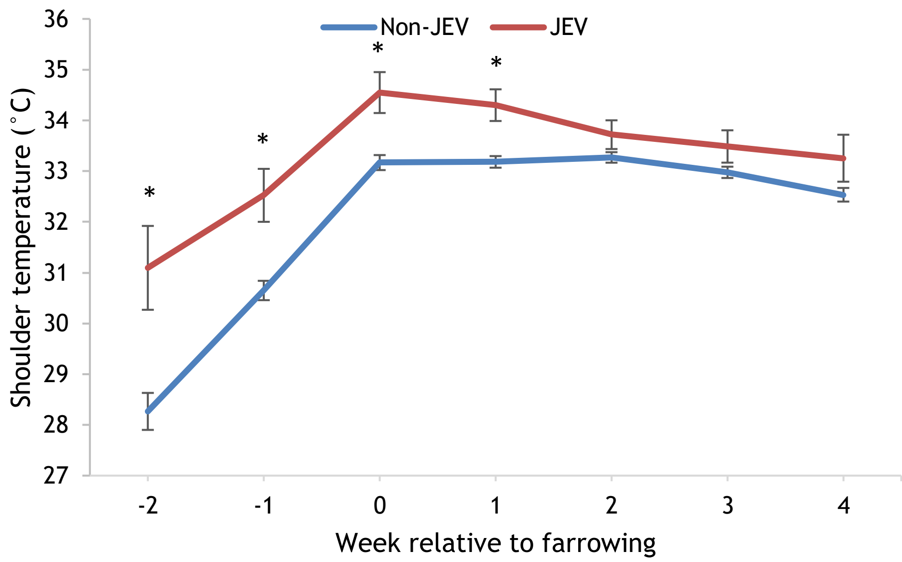



**Fig. 3.2.9:** Average shoulder temperature by week relative to farrowing for sows suffering clinical symptoms of Japanese Encephalitis Virus (JEV; red line) vs. those not showing signs (blue line). JEV status $p < 0.001$, Week $p < 0.001$, JEV*Week $p = 0.008$. *Indicates a significant ($p < 0.05$) difference between JEV status at that timepoint.

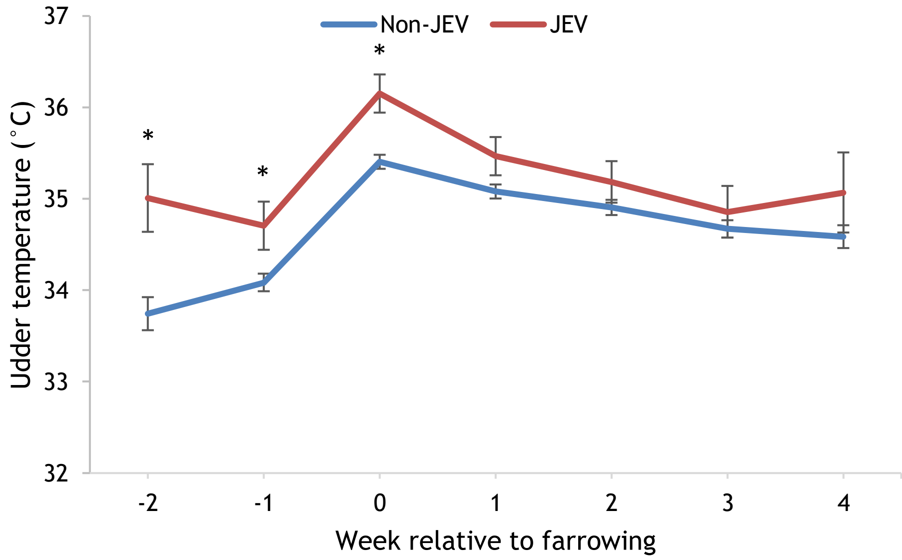



**Fig. 3.2.10:** Average udder temperature by week relative to farrowing for sows suffering clinical symptoms of Japanese Encephalitis Virus (JEV; red line) vs. those not showing signs (blue line). JEV status $p = 0.006$, Week $p < 0.001$, JEV*Week $p = 0.20$. *Indicates a significant ($p < 0.05$) difference between JEV status at that timepoint.

# 4. Application of Research

## *4.1 Skin temperature measured with IRT as an alternative to rectal temperature*

Overall, in our studies, skin temperatures were not well correlated with rectal temperature in sows, in agreement with previous studies (Traulsen et al., 2010; Schmidt et al., 2013). Skin temperatures can be largely influenced by environmental temperature (Sykes et al., 2012), air movement, humidity, ammonia (Soerensen et al., 2014), water, faeces, urine, dirt and dust from the environment (Knizkova et al., 2007). These outside factors were largely not controlled for in the current study. Therefore, it may be unsurprising that correlations with rectal temperature were not high. Recent studies have seen stronger correlations between udder skin temperatures and rectal temperatures (Rosengart et al., 2021; 2022); however, these studies differed from ours in that images were taken of the whole udder rather than a local pointer temperature.

Skin temperatures (mainly ear base) were better correlated with rectal temperature in piglets in Experiment 1. This may present a more non-invasive way to measure body temperature after birth in these vulnerable animals to detect those that may be less viable in the first few critical hours of life, especially given the links to colostrum intake that we saw in our data. However, it must be noted that to read an accurate ear base temperature in piglets in the current study, piglets were required to be picked up by the operator and hence skin temperature measurement in this way was not purely non-invasive.

Under the conditions of the current study, it is not recommended that skin temperatures recorded using IRT replace rectal temperatures in sows or piglets.

## *4.2 Skin temperature and relationships with sow reproductive performance*

In our study, skin temperatures were largely not related to sow reproductive performance in lactation and hence not useful for predicting high (or low) performing sows. Relationships between udder temperatures and number of piglets born alive seen in Experiments 1 and 2 could be related to the number of pigs competing for teats and/or more activity at the udder. Furthermore, the relationship between piglets born alive and vulva temperature may indicate stress during farrowing as more piglets are being born, and this deserves further study.

Before farrowing, udder temperature may be more influenced by postural changes by the sow, and hence there may be a similar explanation for the differences in udder temperatures between BA groupings at these timepoints as with shoulder temperature. However, after farrowing, udder temperature may be more influenced by suckling pressure by piglets and hence may explain why sows with >13 piglets BA showed numerically higher udder temperatures after farrowing in our study. It is possible that udder temperature measured by the thermal camera is influenced by recent suckling by piglets and the act of suckling immediately before image capture could warm the teat surface. On the other hand, milk removal from the udder may cause a reduction in skin temperature after suckling. Indeed, in a study in dairy cattle, udder temperature was reduced by 1°C when measured 1 h after a machine milking (Sathiyabarathi et al., 2016). The time from last suckling bout was not measured in the current project and may therefore be important for consideration in any subsequent work in this area.

Aside from detecting sows with high reproductive performance, IRT shows promise for assisting with oestrus detection in gilts and sows (Scolari et al., 2011; Sykes et al., 2012; Simões et al., 2014) and has been used to confirm pregnancy status in some animals (Durrant et al., 2006; Bowers et al., 2009; Krueger et al., 2019), which may be another area where IRT shows promise for use in a commercial setting. However, there were no significant relationships between skin temperatures and WRI in the current project (data not shown). Relationships between skin temperatures measured in the WRI period and the number of non-productive days per sow may be an interesting relationship for further study.

## *4.3 Skin temperature and relationships with sow health status*

A previous study in sows showed that skin temperatures measured by IRT can be useful in detecting fever (Schmidt et al., 2013) and our results seem to agree. However, it is not recommended that skin temperature alone is used in sows to detect fever (Schmidt et al., 2013).

However, fever or localised temperature increases may indicate mastitis, and measurement of skin temperature of the udder may therefore be useful in its diagnosis. Diagnosing mastitis is currently limited to expensive, invasive (and difficult to use) technology such as ultrasound, Doppler technology and/or biopsies (Peltoniemi et al., 2019), all of which require significant training of the technician and restraint of the animal (and in the case of biopsies, sedation or anaesthesia). If IRT could successfully identify sows experiencing mastitis, health and welfare of sows and their piglets would be improved by early detection and treatment of this condition in lactation. Unfortunately, incidence of mastitis (using our criteria) was not linked to any skin temperatures studied in our experiment. However, IRT has been shown to be an informative tool in detection of mastitis in dairy cattle (Sathiyabarathi et al., 2016; Sinha et al., 2018). Given that sub-clinical mastitis was not diagnosed in our study, the links between udder skin temperature and mastitis incidence in sows deserves to be further investigated.

Our results may suggest that skin temperatures measured by IRT, particularly those of the base of the ear and the shoulder, may be useful in detecting sows that may be impacted by JEV. This finding deserves further study given the recent impact of JEV on Australian farms. This IRT technology provides a non-invasive way to measure body temperature in sows and potentially identify those suffering from fever as a result of JEV in the event of a known outbreak (or could be applicable to other diseases and used hand in hand with other diagnostic techniques) without having to physically handle the animal and potentially risk spreading infections between animals, as is the case with internal rectal temperature measurement (Soerensen and Pedersen, 2015). To our knowledge, there has been little in the published literature investigating relationships between skin temperature and JEV infection in sows, and IRT as an early detection tool for JEV is an important area of interest for the future.

We saw little relationship between shoulder temperature (or other skin temperatures) and formation of shoulder sores in the current study. In contrast, Staveley et al. (2022) recently found that “hot spots” could be seen in IRT images on sows that would later develop shoulder sores in lactation, and could be used to identify these sows approximately 7 days before shoulder sore formation. Hot spots in that study were defined as a local temperature increase over the shoulder as previously identified by Westin and Rydberg (2010). Unfortunately, hot spots were not individually identified in the current study, and this is something that should be further explored with the E8 camera in the future. Care must be taken when IRT is used to capture shoulder temperature, as often in commercial conditions dripper cooling systems can wet the shoulder and hence impact IRT measurements. Indeed, wetting by these systems has been identified as an influencing factor in shoulder sore development (Staveley et al., 2022).

## *4.4 Use of IRT technology in a commercial farrowing house*

From the relationships seen in our study, the skin temperatures measured at the base of the ear, shoulder and the posterior udder were the most reliable for relating to sow reproduction and health measures. This was similar to the results from Schmidt et al. (2013) who found that these locations were least variable between animals, indicating that they may be less impacted by environmental and other outside factors. These were also some of the most suitable images for collection from a practical perspective, with less chance of interference from crates, movement, piglets or other outside factors.

As part of this project, we also planned to use the FLIR System Duo Pro R camera to attempt to measure the thermal temperature, respiration rate and heart rate of a subject simultaneously, whilst recording this data for later analysis (Jorquera-Chavez et al., 2021b). However, analysis of the images and data taken from this camera in Experiment 1 presented complications with recording and extracting the data and no meaningful links were able to be derived between the measures taken with this camera and sow performance. Position and movement of the sow in the farrowing crate also presented difficulties for measuring heart rate and respiration rate, which relies on accurate recording of sow movements over a considerable period of time. These measurements can be greatly influenced by motion and light conditions (Sikdar et al., 2016), as well as distance from the animal (Johnson et al., 2011), and other factors that could not be controlled for easily in a commercial farrowing house.

These IRT technologies may be more useful in detection of pigs who are experiencing body temperatures outside normal ranges (e.g., outside the limits of thermal comfort). For example, IRT images have been shown to be useful for assessment of cooling sprinkler systems on maintenance of body temperature in pigs (Caldara et al., 2014). Once farmers have invested in IRT technologies such as the E8 camera, they can be used for various functions outside of detection of sow health and reproductive performance. For example, IRT is frequently used to check ventilation in pig sheds and/or monitor for any gaps or damage to insulation caused by rats (Hess, 2022).

# 5. Conclusion

In conclusion, overall skin temperatures measured on sows and piglets were not overly indicative of reproductive performance or health status in sows or piglets. Nevertheless, use of IRT tools such as the FLIR E8 Series camera offer an effective non-invasive way to measure sow skin temperatures in comparison to rectal temperature; nevertheless, rectal temperature remains the gold standard to measure internal body temperature in sows and piglets. Skin temperatures taken at the base of the ear, shoulder and/or posterior teats of the udder may be the best areas to indicate changes in body temperature in sows and piglets.

Eventually, it is hoped that this IRT technology can be used to help develop algorithms that can be adapted for on-farm use. Given the large amount of data collected and stored as a result of this project, an ongoing Masters project conducted by Buddhika Liyanage at The University of Melbourne aims to further analyse this data in relation to other sow performance measures and possible impacts of heat stress and posture changes of sows in farrowing crates.

# 6. Limitations/Risks

Interpretation of thermal images and image data presents a number of risks associated with operator error. Risks identified within the current project include:

- Operator error with selecting the desired area of the image at image capture and within the Matlab program;
- Movement of the camera – takes 'blurry' images, thermal signature and actual image don't overlap completely (which causes difficulty with selecting the desired area on the Matlab program);
- Distance between camera and location on the animal that is being photographed (can be impacted by user, environment, bars getting in way etc.);
- Water and other aspects in the environment impacting the emissivity of the skin (from cooling drippers, air conditioners etc.).

Operator error or environmental factors can easily result in a bad quality image, and hence correct training in the use of the cameras is essential. Some examples of bad quality images are shown in Fig. 6.1, Fig. 6.2 and Fig. 6.3, where the thermal image does not line up properly with the image subject, the subject in the image has moved resulting in incorrect temperature measurement, and where piglets or other objects can get in the way of the area you are trying to visualise (respectively).

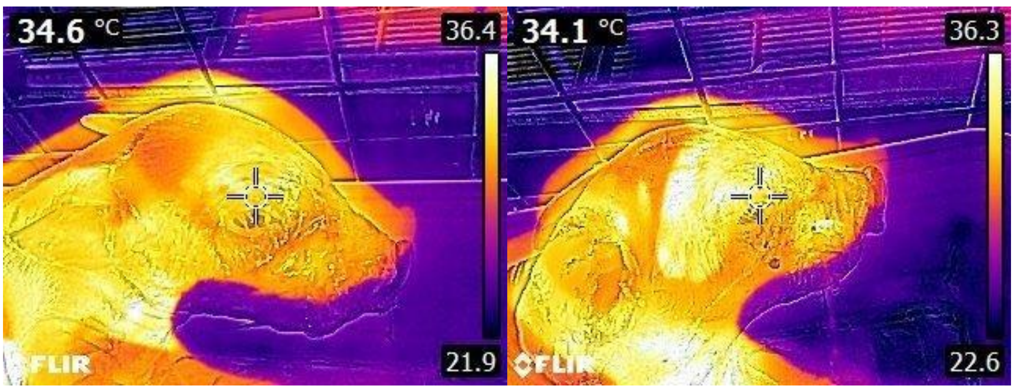



**Fig. 6.1:** Examples of images where thermal signature doesn't line up directly with the subject in the image (piglet).


**Fig. 6.2:** Example of an image where the subject has moved and the temperature reading at the pointer may not be accurate.

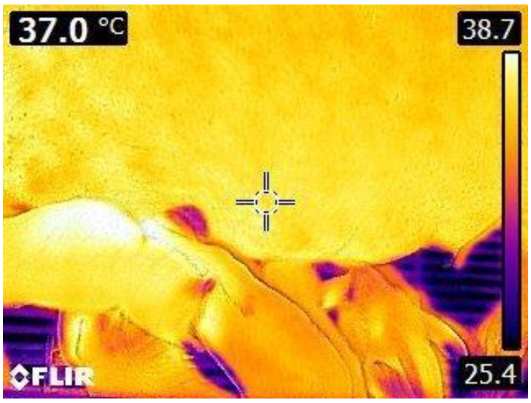



**Fig. 6.3:** Piglets, bars, heat lamps or other aspects of the farrowing crate can often get in the way of the image. This presents problems with analysing the average temperature of the whole image.

All of these factors need to be taken into consideration when using hand-held IRT devices on farm and analysing data with computer programs such as MatLab. Future work should focus on developing algorithms to take remote images of desired areas on sows and piglets, and also to automate the selection of desired areas, keeping consistent between images.

# 7. Recommendations

As a result of the outcomes in this study the following recommendations have been made:

1. Thermal cameras such as the FLIR E8 be used to complement rectal temperature of sows in lactation as a non-invasive way to measure body temperature;
2. That skin temperatures be measured at the point of the shoulder, ear base and posterior teats when IRT technologies are used in a commercial farrowing house;
3. That thermal cameras may be used to measure shoulder, udder and/or ear base temperature when assessing sows for impacts of confirmed JEV around farrowing in the event of an outbreak; and,

4. That the cost of this thermal camera technology is made more affordable in the future for commercial producers.

The following publications arose from this project:

- Jorquera-Chavez M., Craig J.R., Tucker B.S., Gardiner N.C. and Morrison R.S. (2021). 24. The effect of farrowing crate heat lamps on the skin and rectal temperature of sows. Animal-science proceedings 12, 186. (Australasian Pig Science Association Conference, Brisbane).
- Tucker B.S., Jorquera-Chavez M., Petrovski K.R., Craig J.R., Morrison R.S., Smits R.J. and Kirkwood R.N. (2023). Comparing surface temperature locations with rectal temperature in neonatal piglets under production conditions. Journal of Applied Animal Research, 51(1):212-219.
- Lewis M. (2022). Use of infrared thermography to detect changes in body temperature of sows in a commercial farrowing house. Thesis, Master of Agricultural Science, The University of Melbourne.
- Liyanage B.P., Jorquera-Chavez M., Craig J.R., Murden D., McGill D. and Jongman E.C. (submitted). Validation of detecting mastitis in lactating sows using udder temperature measured with infrared thermographic camera technology: A pilot study. Submitted as a one-page paper to the Joint AAAS-AAAP Animal Production Congress, Melbourne July 2024.

# 8. Acknowledgements

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# Appendices

## *Appendix 1: Standard operating procedure (SOP) for Measuring eye and ear temperature with the FLIR E8 thermal camera*

# STANDARD OPERATING PROCEDURE

**Purpose: To accurately measure eye and skin (ear) temperatures using thermal imaging in pigs.**

## Before You Start

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| Before taking photos for a particular sow/litter, it is a good idea to **take a photo of the sows litter card, the piglets' tag, a piece of paper, or a white board** with what sow/piglet that is, the date, and any other relevant information – so this is obvious when the photos are downloaded. Also note down the time that each picture was taken. |
| ALWAYS make sure you keep a **similar distance away** from the part you're measuring every time for each measurement, take a 30 cm ruler with you. The accuracy of the camera temperatures may be different at different distances; hence we want to stay at a similar distance for every reading. |
| Keep the camera **charged** – may lose power quickly when in use. |
| Cameras, iPhone and attachments can get **hot when in use**, take care when picking up cameras if they have been on or charging for a long time. |

## Procedure

| | | |
|---|---|---|
| 1 | Turn the camera on at the power button (Figure 1) and open the lens cover at the front using the lever. | <br>**Figure 1: Power on button on the E8 Camera** |
| 2 | With this camera, you will either need to be measuring with the centre spot, the hot spot, or the cold spot.<br>- To switch modes on the E8 thermal camera (Figure 2), press the middle square button on the back of the camera → Measurement → Hot spot/Cold spot. The camera will then automatically locate the coldest or hottest part of the vulva within the view of the camera. | <br>**Figure 2: Switching through centre, hot and cold spot measurements on the E8 camera** |

<table>
<tr>
<td>3</td>
<td>Make sure the emissivity of the camera is set to 0.985, which has been reported as the emissivity of humans and other mammals' skin (0.98 ± 0.01; Bernard et al., 2013; Hoffmann et al., 2013).</td>
<td>Follow this procedure:<br>1. Push the center of the navigation pad. This displays a toolbar.<br>2. On the toolbar, select Settings. This displays a dialog box.<br>3. In the dialog box, select Measurement parameters. This displays a dialog box.<br>4. In the dialog box, select Emissivity. This displays a dialog box.<br>5. In the dialog box, select Custom value. This displays a dialog box where you can set a custom value.<br><br>Figure 3: Changing the emissivity as a custom value</td>
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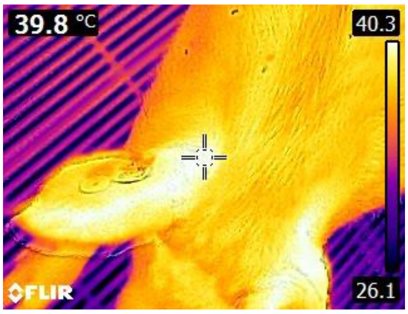
<tr>
<td>4</td>
<td>To measure the thermal temperature at the base of the ear (outside), hold the camera about 30 cm away from the surface of the ear (stay the same distance each time). Take the photo at the base of the ear as shown in Figure 4 using the trigger button on the front of the camera under the lens. Save the image if necessary – or read the centre spot temperature that is recorded in the top left corner of the image (39.8°C in Figure 4).<br><br>Avoid having any ear tags in the way of the centre spot, if possible.</td>
<td>

Figure 4: Centre spot photo of the base of the pig’s ear</td>
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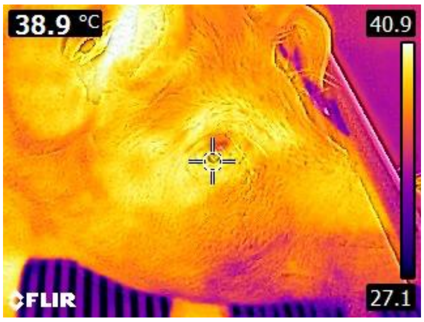
<tr>
<td>5</td>
<td>Hold the camera about 30 cm away from the eye and take a photo as per step 5 (see Figure 5). Try to use the same eye (or ear) for each subsequent reading.</td>
<td>

Figure 5: Centre spot photo of the pig’s eye</td>
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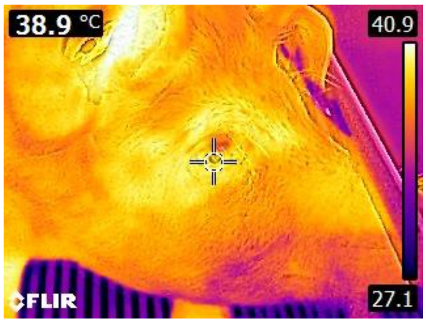
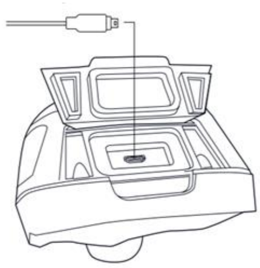
| | | |
|---|---|---|
| 5 | Hold the camera about 30 cm away from the eye and take a photo as per step 5 (see Figure 5). Try to use the same eye (or ear) for each subsequent reading. | <br>**Figure 5: Centre spot photo of the pig's eye** |
| 6 | To download images onto the computer:<br>□ Connect the USB mini-B connector to the camera (Figure 6) and the USB cable connected to a computer → the camera will appear as a folder → select this folder or the images to be downloaded → Copy → paste in the relevant folder for data extraction later. | <br>**Figure 6: Connect the USB mini-B connector to the camera** |
| 7 | To delete photos from the camera:<br>□ select the image first → press the middle square button on the back of the camera → select Delete (Figures 7 and Figure 8)<br><br>Be aware that the E8 camera can hold approximately 1,008-1,017 photos, after which point it will not save any more images until there is sufficient memory to do so (no warning on the screen). | Follow this procedure:<br>1. Push the Archive button .<br>2. Push the navigation pad left/right or up/down to select the image you want to view.<br>3. Push the center of the navigation pad. This displays the selected image.<br>4. Push the center of the navigation pad. This displays a toolbar.<br>5. On the toolbar, select *Delete* .<br>**Figure 7: Deleting an image**<br><br>Follow this procedure:<br>1. Push the center of the navigation pad. This displays a toolbar.<br>2. On the toolbar, select *Settings* . This displays a dialog box.<br>3. In the dialog box, select *Device settings*. This displays a dialog box.<br>4. In the dialog box, select *Reset options*. This displays a dialog box.<br>5. In the dialog box, select *Delete all saved images*.<br>**Figure 8: Deleting all images** |

## Before You Finish

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| **Take note** of things that you think might have an impact on the reading; e.g. are heaters on, are the piglets wet, does the pig have excessive hair in the area you're trying to measure? |
| **Download all photos** at the end of the day to the computer (even more frequently if necessary) and make space on the camera for the next day. Organise the photos for easy identification later on in a folder labelled with the Camera/Day/Time period being recorded. |
| Remember to turn the camera off and close the lens cover when finished. |

END OF STANDARD OPERATING PROCEDURE