Effect of drying and/or warming piglets at birth under warm farrowing room temperatures on piglet rectal temperature over the first 24 h after birth

Katherine D. Vande Pol,[†,] Andres F. Tolosa,[†] Caleb M. Shull,[‡] Catherine B. Brown,[‡] Stephan A. S. Alencar,[‖] Clay A. Lents,[§] and Michael Ellis[†,1]

[†]Department of Animal Sciences, University of Illinois, Urbana-Champaign, IL 61801, USA; [‡]The Maschhoffs, LLC, Carlyle, IL 62231, USA; [‖]Departamento de Zootecnia, Federal University of Mato Grosso do Sul, Campo Grande, MS 79070-900, Brazil and; [§]USDA, ARS, U.S. Meat Animal Research Center, Clay Center, NE 68933, USA

ABSTRACT: Piglets experience a decline in body temperature immediately after birth, and both drying and warming piglets at birth reduce this. However, these interventions may be less effective at higher farrowing room temperatures. This study was carried out at a commercial facility to compare the effect of drying and/or warming piglets at birth on postnatal rectal temperature (**RT**) under relatively warm farrowing room temperatures (26.6 ± 2.09 °C). Forty-five sows/litters were used in a completely randomized design to compare three Intervention Treatments (applied at birth): Control (no treatment); Warming (piglets placed in a plastic box under a heat lamp for 30 min); and Drying+Warming (piglets dried with desiccant and warmed as above). Temperatures in the warming boxes over the study period averaged 37.7 ± 2.75 °C. At birth, piglets were weighed; RT temperature was measured at 0, 10, 20, 30, 45, 60, 120, and 1,440 min after birth. Blood samples were collected at 24 h after birth from a subsample of one piglet from each birth weight quartile within each litter to measure plasma immunocrit concentration. Data were analyzed using PROC MIXED of SAS with litter as the experimental unit, and piglet as a subsample of litter. The model for analysis of piglet rectal temperature included fixed effects of Intervention Treatment, measurement time (repeated measure), the interaction, and the random effect of sow. Compared with the Control, piglet RT were higher ($P \leq 0.05$) for the Warming treatment between 10 and 60 min, and higher ($P \leq 0.05$) for the Drying+Warming treatment between 10 and 120 min after birth. Rectal temperatures were higher ($P \leq 0.05$) for the Drying+Warming than the Warming treatment between 20 and 120 min. Responses to drying and/or warming were greater for low-birth-weight piglets (<1.0 kg) than heavier littermates, but were generally less than observed in previous experiments with similar treatments carried out under cooler temperatures. Piglet immunocrit values were lower ($P \leq 0.05$) for the Drying+Warming treatment compared to the other Intervention Treatments, which were similar ($P > 0.05$). Immunocrit values tended ($P = 0.10$) to be lower for light (<1.0 kg) compared with heavier birth weight piglets. In conclusion, drying and warming piglets at birth was more effective for reducing piglet RT decline after birth than warming alone, though the effect was less than observed in previous studies carried out under cooler farrowing room temperatures.

Key words: drying, farrowing, piglet, rectal temperature, room temperature, warming

[1]Corresponding author: mellis7@illinois.edu

Received November 12, 2020.
Accepted March 31, 2021.

Transl. Anim. Sci. 2021.5:1-12
doi: 10.1093/tas/txab060

INTRODUCTION

Farrowing facilities house both sows and piglets, which have markedly different thermal requirements. Newborn piglets have a high surface area to body volume ratio, little body surface insulation, and limited capacity for thermoregulatory heat production, resulting in a high critical temperature of around 35 °C and a relatively narrow thermoneutral zone (Mount, 1959). However, sows have a lower surface area to body volume ratio, greater body surface insulation, and higher levels of heat production, resulting in a substantially lower thermoneutral zone (15 to 20 °C; Black et al., 1993). At higher ambient temperatures (e.g., ≥25 °C), sows show signs of heat stress, including increased respiration rates and higher rectal temperatures, and experience longer farrowing duration (Muns et al., 2016). As a compromise between the thermal requirements of the sow and piglet, it is generally recommended that farrowing room temperatures on commercial facilities should be kept at around 22 °C on the day of farrowing (PIC, 2018). At these temperatures, newborn piglets experience considerable heat loss from the body surface due to convection and radiation and also because of evaporation of amniotic fluids. Therefore, in the absence of any intervention, all piglets will experience some degree of hypothermia under typical commercial conditions (Vande Pol et al., 2020, 2021). This predisposes piglets to mortality both directly and from secondary causes such as starvation, crushing, and disease (Devillers et al., 2011). Low-birth-weight piglets are particularly at risk of hypothermia because of the higher body surface to body volume ratio and, therefore, have a relatively greater potential to lose more heat than heavier littermates (Herpin et al., 2002).

One approach to limiting piglet heat loss without increasing farrowing room temperature is to provide a localized heated area in the farrowing pen, using, for example, heat lamps. Although this is a common commercial practice, newborn piglets are generally not confined to the heated area and are often more attracted to the sow in the early postnatal period (Houbak et al., 2006; Pedersen et al., 2006). A warming box (a box that includes a heat source) can be utilized to confine piglets to a heated area for short periods of time after birth (typically between 15 and 30 min) to minimize heat loss. Another method of limiting early postnatal heat loss is through drying piglets at birth, thereby minimizing the evaporation of amniotic fluids and associated heat loss from the body surface. Vande Pol et al. (2021) showed that both drying piglets with a desiccant and placing them in a warming box for 30 min after birth were similarly effective at reducing piglet temperature decline in the early postnatal period. However, the combination of these two approaches was more effective than either one applied separately.

There is evidence of a positive association between piglet rectal temperature in the early postnatal period and both the time to first suckling (Kammersgaard et al., 2011) and, also, serum immunocrit concentration at 24 h after birth (Devillers et al., 2011). Serum immunocrit concentration measured on the day after birth is an index of colostrum intake (Vallet et al., 2015). Inadequate colostrum intake in piglets in the early period after birth increases the risk of preweaning mortality (Devillers et al., 2011). Some studies have also found that drying piglets at birth reduced the time to first suckling (Vasdal et al., 2011); however, others reported no effect of drying or warming on this measurement (Christison et al., 1997). There are no published studies investigating the effect of drying and/or warming of piglets at birth on serum immunocrit concentration.

Although both drying and warming of newborn piglets have been used in commercial practice, there has been little published research on the effects of these approaches, used either singly or in combination, on piglet temperatures during the early postnatal period. In addition, most published studies have been carried out with farrowing room temperatures between 18 and 22 °C (e.g., Le Dividich and Noblet, 1981; Vande Pol et al., 2020, 2021). However, temperatures in farrowing rooms can be considerably higher, particularly during the warmer periods of the year, often exceeding 28 °C (Koketsu et al., 1996). These higher temperatures are likely to result in reduced heat loss from newborn piglets, and therefore, it is important to determine whether drying and/or warming of piglets at birth are as effective at moderating postnatal temperature decline under such conditions.

MATERIALS AND METHODS

This study was conducted in the farrowing facilities of a commercial breed-to-wean farm of The Maschhoffs, LLC, located near Crawfordsville, IN, during the months of August and September. The experimental protocol was approved by the University of Illinois Institutional Animal Care and Use Committee prior to the initiation of the research.

Animals, Experimental Design, Treatments, and Allotment

A total of 45 sows and litters (603 piglets) were used in the study. Sows were from commercial dam lines of Yorkshire and Landrace origin that had been mated to commercial sire lines. A completely randomized design was used, with litter as the experimental unit and piglet as a subsample of the litter, to compare three Intervention Treatments (applied at birth): Control (no intervention); Warming (piglets placed in a plastic warming box under a heat lamp for 30 min; mean temperature in the box over the study period was 37.7 ± 2.69 °C); Drying+Warming (piglets were dried by coating with a commercial cellulose-based desiccant until completely dry, then warmed as above; mean temperature in the warming box over the study period was 37.6 ± 2.85 °C). Sows/litters were randomly allotted to Intervention Treatments at the start of farrowing, with the restriction that dam genotype and parity were balanced across treatments.

Housing and Management

Each sow was housed in an individual farrowing crate, located in the center of a farrowing pen. The flooring of the pen was of either woven metal or perforated plastic depending on the room being used. The number of sows that were housed in pens with each flooring type was similar across treatments. Crate dimensions were 0.55 m wide by 1.95 m long, giving a floor space within the crate of 1.07 m^2; pen dimensions were 1.52 m wide by 2.07 m long, giving a total pen floor space of 3.15 m^2. Crates were equipped with a sow-operated feed dispenser attached to a feed trough, and a nipple-type water drinker for the sow. An infrared heat lamp was suspended in the center of the floor area on one side of the farrowing crate over an insulated rubber mat (average temperature under the heat lamp during the study period was 38.1 ± 3.13 °C). For the Intervention Treatments that used a warming box, this heat lamp was suspended over the box throughout the duration of farrowing. Box dimensions were 64.1 cm long by 43.8 cm wide by 38.7 cm deep (Sterilite Corporation; Townsend, MA). The piglets were placed in the warming box immediately after birth, removed after 30 min, and returned to the farrowing pen. Room temperature was maintained using heaters, evaporative cooling cells, and fan ventilation as needed; room thermostats were set at 22.5 °C throughout the study period.

Management in the farrowing facility was according to unit protocols, which were in line with standard commercial practices. Sows that had not farrowed by d 116 of gestation were induced to farrow on the following day using Lutalyse (1 injection of 1 mL given at 0600 h; Zoetis; Parsippany, NJ); the identity of each sow induced and date of induction were recorded. The farrowing process was monitored continuously by the investigators; if the interval between the births of piglets exceeded 60 min, the investigator checked the birth canal for obstructions, and assisted the farrowing process as needed.

Procedures and Measurements

Sow rectal temperature was measured at the start and end of the farrowing process, and sow parity and litter size were recorded. At birth, piglets were given a uniquely numbered ear tag for identification, and treatments were applied; piglet rectal temperature was measured at 0, 10, 20, 30, 45, 60, 120, and 1,440 min after birth. After the Intervention Treatments were applied, piglets were returned to the farrowing pen (immediately for the Control and after 30 min in the warming box for the other two Intervention Treatments), being placed at the udder of the sow. Piglets were weighed within 12 h of birth using a Brecknell LPS-15 bench scale (Avery Weigh-Tronix; Fairmont, MN). Scales were calibrated prior to each use with a standard test weight.

Piglet and sow rectal temperatures were measured at a depth of 2.5 cm and 10 cm, respectively, using a HSTC-TT-K-24S-36 thermocouple attached via a SMPW-K-M connector to a dual input K/J digital thermometer (HH801A; Omega; Stamford, CT). Thermometers were calibrated each week during the study period by taking measurements in a temperature-controlled chamber that was set at temperatures that encompassed the expected range (i.e., 30, 32, 34, 36, 38, and 40 °C). A regression equation was developed between measured and set temperatures, and this equation was used to adjust all rectal temperature measurements taken during the following week of the study period.

The temperature in each farrowing pen was measured at three locations (behind and at either side of the sow) at the beginning and end of the farrowing process. One of these measurements was under the heat lamp, which was located either over the warming box for the Warming and Drying+Warming treatments, or over the insulated mat for the Control treatment. These temperatures

were measured with a digital infrared thermometer (TOOGOO GM320 LCD digital infrared thermometer gun [Shenzhen IMC Digital Technology Co. Shenzhen, China]).

Blood samples to measure serum immunoglobulin immunocrit concentrations were obtained at 24 h after birth from a subsample of four piglets from each litter (one piglet randomly selected from each birth weight quartile of each litter). A 2-mL blood sample was collected from the abdominal vein into plain glass tubes, immediately placed on ice, and subsequently centrifuged (for 30 min at 3,000 × *g*). Serum was obtained and stored at −20 °C prior to analysis for immunoglobulin immunocrit concentration as previously validated and described (Vallet et al., 2013).

Statistical Analysis

The litter of piglets was the experimental unit for all measurements; piglet was a subsample of litter. The PROC UNIVARIATE procedure of SAS (SAS Inst. Inc., Cary, NC) was used to verify normality and homogeneity of variances of the residuals. All variables conformed to the assumptions of normality and homogeneity and were analyzed using the PROC MIXED procedure of SAS (Littell et al., 1996). Data were analyzed as a completely randomized design using a model for the analysis of sow and litter parameters which accounted for the fixed effect of Intervention Treatment. The model used for analysis of treatment differences in piglet birth weight and serum immunoglobulin immunocrit concentration also included the random effect of litter.

Treatment effects on piglet rectal temperatures at the various measurement times after birth were analyzed using a repeated measures analysis, using a model that accounted for the fixed effects of Intervention Treatment, measurement time, and the interaction, and the random effect of litter. A repeated-measures statement was included in the model with measurement time as the REPEATED term and piglet within litter as the SUBJECT term.

The study of Vande Pol et al. (2021) used three of the same Intervention Treatments as the current study and was carried out in the same facilities with identical methodology. However, the experiment of Vande Pol et al. (2021) was carried out at a cooler time of year (February and March), when farrowing room temperatures were lower (21.8 ± 1.80 °C) than in the current study (26.6 ± 2.09 °C), which was carried out in August and September. The effect of Farrowing Room Temperature (**FRT**) on changes in piglet rectal temperature after birth was evaluated by combining the datasets from these two studies, which were classified as being under either COOL (Vande Pol et al., 2021) or WARM (the current study) FRT. The change in piglet rectal temperature over the first 2 h after birth relative to temperature at birth (temperature at each measurement time minus temperature at birth) was analyzed using a statistical model that included the fixed effects of FRT, Intervention Treatment, and the interaction, and the random effect of piglet within litter.

An analysis was carried out to determine if the response to Intervention Treatments differed according to piglet birth weight. Data were divided into Light (<1.0 kg; 0.81 ± 0.138 kg), Medium (1.0 to 1.5 kg; 1.29 ± 0.136 kg), or Heavy (>1.5 kg; 1.72 ± 0.176 kg) Birth Weight Category treatments (**BWC**). The maximum weight for the Light category (i.e., 1.0 kg) represented the birth weight below which pre-weaning mortality increases substantially (Zotti et al., 2017). The minimum weight for the Heavy category (i.e., 1.5 kg) represented the weight above which pre-weaning mortality is relatively unaffected by birth weight (Zotti et al., 2017). Piglet rectal temperature data at each measurement time were analyzed using a statistical model that included the fixed effects of BWC, Intervention Treatment, and the interaction, and the random effect of piglet within litter.

For all analyses, differences between least-squares means were separated using the PDIFF option of SAS, being considered significant at $P \leq 0.05$. All *P*-values were adjusted using a Tukey's adjustment for multiple comparisons.

RESULTS AND DISCUSSION

Sow and litter parameters and farrowing pen temperatures have been summarized by Intervention Treatment in Table 1. There were no differences ($P > 0.05$) between treatments for any of these parameters or measurements. In general, the sows and litters used in the study were typical of U.S. commercial production. The majority of sows were between parities 1 and 8. Average number of piglets born alive per litter (12.9 to 14.3) were similar to values for U.S. herds reported at the time this study was conducted (13.2 piglets; PigChamp, 2018). Sow temperatures before and after farrowing averaged between 38.6 and 39.4 °C, which is typical for farrowing sows (Littledike et al., 1979). Farrowing pen temperatures, which averaged between 25.1 and 28.2 °C (Table 1), were higher than the set point (22.5 °C). These temperatures were expected, as the

Table 1. Summary of sow and litter parameters and farrowing pen temperatures during the study by Intervention Treatment

	Intervention Treatment[1]				
Item	Control	Warming	Drying+Warming	SEM	*P*-value
Number of sows	15	15	15	—	—
Average sow parity[2]	2.9	2.9	2.8	0.67	0.99
Number of piglets born alive					
Total	195	215	193	—	—
Average per litter	13.0	14.3	12.9	0.84	0.40
Piglet birth weight (born alive), kg	1.41	1.39	1.44	0.023	0.31
Sow rectal temperature, °C					
Start of farrowing	38.62	38.85	38.79	0.116	0.34
End of farrowing	39.02	39.23	38.99	0.121	0.33
24 h after farrowing	39.38	39.38	39.11	0.155	0.40
Farrowing pen temperature, °C					
Start of farrowing					
Under heat lamp[3]	37.33	36.80	36.81	0.663	0.82
Side of pen opposite heat lamp	25.81	25.42	26.25	0.516	0.54
Behind sow	25.43	25.07	25.93	0.448	0.40
End of farrowing					
Under heat lamp[3]	38.85	38.42	38.51	0.816	0.92
Side of pen opposite heat lamp	27.72	27.71	28.15	0.514	0.79
Behind sow	27.18	26.97	27.54	0.498	0.77

[1]Control = no treatment; Warming = placed in a plastic box under a heat lamp for 30 min; Drying+Warming = dried with desiccant and placed in a plastic box under a heat lamp for 30 min.

[2]Parity = total number of litters including the one used in the study.

[3]Measurements under the heat lamp were within the warming boxes for the Warming and Drying+Warming treatments, and under the lamp on the insulated mat for the Control.

study was conducted during the summer months when it was not possible to maintain farrowing room temperatures at the set point.

The least-squares means for the effects of drying and/or warming on piglet rectal temperature over the first 24 h after birth are presented in Table 2. Temperatures at birth were similar ($P > 0.05$) for the three Intervention Treatments and were within the range reported in previous research (i.e., between 37.0 and 41.5 °C; Kammersgaard et al., 2011; Pomeroy, 1953; Vande Pol et al., 2020, 2021). There were differences ($P \leq 0.05$) between Intervention Treatments in piglet rectal temperature at all measurement times between 10 and 1440 min after birth (Table 2). For the Control treatment, which provided an estimate of temperature changes in untreated piglets, the minimum rectal temperature was at 30 min after birth (Table 2), which is in agreement with a number of studies that have measured temperature decline of untreated piglets (Andersen and Pedersen, 2015; Cooper et al., 2019; Vande Pol et al., 2020, 2021). However, reported values for this minimum temperature have varied widely between studies, from

Table 2. Least-squares means for the effect of Intervention Treatment on the rectal temperature of piglets over the first 24 h after birth

	Intervention Treatment[1]				
Item	Control	Warming	Drying+ Warming	SEM	*P*-value
Number of litters	15	15	15	—	—
Piglet rectal temperature, °C					
Time after birth, min					
0	39.12	39.14	39.02	0.036	0.33
10	37.38[b]	37.90[a]	38.08[a]	0.036	<0.0001
20	36.79[c]	37.67[b]	38.12[a]	0.036	<0.0001
30	36.66[c]	37.76[b]	38.28[a]	0.036	<0.0001
45	36.92[c]	37.73[b]	38.42[a]	0.036	<0.0001
60	37.32[c]	37.94[b]	38.57[a]	0.036	<0.0001
120	38.09[b]	38.35[b]	38.75[a]	0.036	<0.0001
1,440	38.76[b]	39.01[a]	38.84[ab]	0.038	0.02

[a,b,c]Within a row, means with differing superscripts differ ($P \leq 0.05$).

[1]Control = no treatment; Warming = placed in a plastic box under a heat lamp for 30 min; Drying+Warming = dried with desiccant and placed in a plastic box under a heat lamp for 30 min.

33.6 °C (Xiong et al., 2018) to 36.6 °C (Pattison et al., 1990). The minimum temperature observed for the Control treatment in the current study was greater than that found in previous research (e.g., Cooper et al., 2019; Vande Pol et al., 2020, 2021), which was most likely because of the higher farrowing room temperatures experienced during this study. However, the maximum decline in rectal temperature of the untreated Control piglets was 2.5 °C, and, therefore, these piglets still experienced hypothermia, even at these relatively high farrowing room temperatures.

Compared to the Control, rectal temperatures of piglets were higher ($P \leq 0.05$) for the Warming treatment between 10 and 60 min and higher ($P \leq 0.05$) for the Drying+Warming treatment between 10 and 120 min (Table 2). Temperatures were also greater ($P \leq 0.05$) for the Drying+Warming than the Warming treatment between 20 and 120 min. Relative to the Control treatment, minimum temperatures for the Warming and Drying+Warming treatments were reached earlier (at 30, 20, and 10 min after birth, respectively) and were higher (36.7, 37.7, and 38.1 °C, respectively). These results suggest that warming piglets reduced the extent and duration of rectal temperature decline of piglets in the early postnatal period, and, also, that this approach was more effective when combined with drying.

At 1440 min after birth, the Warming treatment resulted in a higher ($P \leq 0.05$) temperature than the Control, with the Drying+Warming treatment being intermediate and not different ($P > 0.05$) to the other two Intervention Treatments (Table 2). However, treatment differences were relatively small (≤0.3 °C) and rectal temperatures of piglets on all treatments approached those at birth. Most studies have shown that piglet temperatures approach levels observed at birth by 24 h after birth (McGinnis et al., 1981; Pattison et al., 1990; Xiong et al., 2018; Vande Pol et al., 2020, 2021).

Published studies relating to the effect of warming of piglets at birth on postnatal change in rectal temperature are limited in number and vary considerably in methodology. In some studies, additional heat sources were provided in the farrowing pen without confining piglets to the heated area (McGinnis et al., 1981; Vasdal et al., 2011; Andersen and Pedersen, 2015). This approach resulted in relatively small differences in piglet rectal temperatures compared to those from litters without an additional heat source (≤0.8 °C across these studies at all measurement times within the first 24 h after birth). The effect of confining piglets to a localized heated area for a period of time after birth was evaluated in three studies. Pedersen et al. (2016) and Vande Pol et al. (2021) found that confining newborn piglets under a radiant heat source (at 34 to 36 °C for 2 h and 30 min after birth, respectively) increased the minimum rectal temperature of the piglets by between 1.2 and 1.7 °C compared to those kept at ambient room temperature. These responses are generally similar to those found in the current study. In contrast, Pattison et al. (1990) found a much smaller increase in rectal temperature (0.3 °C at 60 min after birth) when confining piglets to a heated creep area for 45 min. However, the warming treatment in that study started at 15 min after birth, which may explain the relatively limited response, particularly given that all studies have shown that temperatures of untreated piglets decline rapidly immediately after birth. The general conclusion from these studies is that confining piglets to a heated area immediately after birth was more effective at reducing postnatal temperature decline than adding a heat source to the farrowing pen without piglet confinement.

Although it has been shown in a number of studies that drying of piglets at birth reduces the extent and duration of postnatal decline in rectal temperature (e.g., Berbigier et al., 1978; Cooper et al., 2019; Vande Pol et al., 2020, 2021), only one study has evaluated the combination of drying and warming. Similar to the results of the current study, Vande Pol et al. (2021) found that the combination of drying and warming was more effective at minimizing the postnatal decline in piglet rectal temperature than either approach applied separately. However, these effects on piglet rectal temperatures were relatively greater in the study of Vande Pol et al. (2021) than in the current study.

The results for the effect of Intervention Treatment and FRT on the change in piglet rectal temperature from birth to each measurement time to 2 h after birth are presented in Figure 1. These changes illustrate the initial decline and subsequent recovery in piglet rectal temperature. There were Intervention Treatment by FRT interactions ($P \leq 0.05$) for changes in temperature at all measurement times, except between birth and 10 min after birth (Figure 1). Within each FRT, the change in piglet rectal temperature relative to birth temperature up to 60 min after birth was greater ($P \leq 0.05$) for the Control than the other two Intervention Treatments, and was generally greater ($P \leq 0.05$) for the Warming than the Drying+Warming treatment (Figure 1). In addition, for the Control treatment, the changes

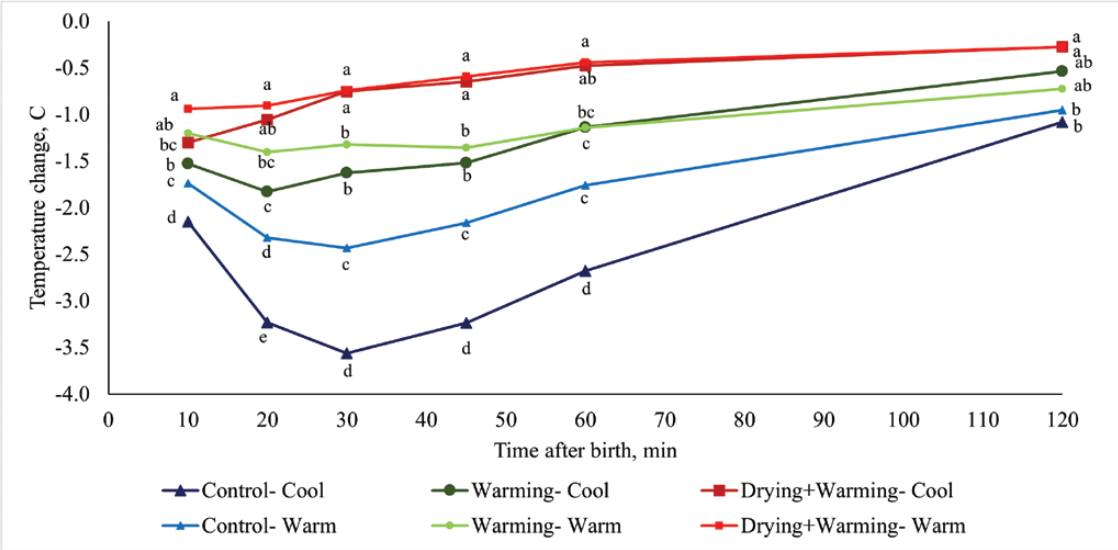

Figure 1. Least-squares interaction means[1] for the change in piglet rectal temperature from birth to subsequent measurement times within the first 2 h after birth, within Farrowing Room Temperature (FRT)[2] and Intervention Treatment (IT)[3]. [a,b,c,d]Within each time after birth, points with differing superscripts differ ($P \leq 0.05$). [1]There were Intervention Treatment × Farrowing Room Temperature interactions ($P \leq 0.05$) for all measurement times with the exception of 10 min after birth. [2]Cool = data from study of Vande Pol et al. (2021), carried out from January to March (farrowing room temperature 21.0 ± 1.65°C); Warm = data from the current study, carried out from August to September (farrowing room temperature 25.3 ± 1.67°C). [3]Control = no treatment; Warming = placed in a plastic box under a heat lamp for 30 min; Drying+Warming = dried with desiccant and placed in a plastic box under a heat lamp for 30 min.

in rectal temperature were greater ($P \leq 0.05$) under COOL compared to WARM FRT at all of these measurement times (Figure 1). In contrast, changes in piglet rectal temperature for the Warming and Drying+Warming treatments were generally similar ($P > 0.05$) for the two FRT during the first 120 min after birth. The exception to this was for the change in rectal temperature between birth and 10 min for the Drying+Warming treatment, which was greater ($P \leq 0.05$) under COOL than WARM FRT (Figure 1). An additional analysis was conducted to compare the rate of change of piglet rectal temperature for each Intervention Treatment between selected measurement times (data not reported). For the Control treatment, the rate of change in rectal temperature between birth and 30 min after birth was greater ($P \leq 0.05$) under COOL (-0.119 °C/min) than WARM (-0.081 °C/min) FRT. In contrast, the rates of change in rectal temperature for this time period were similar ($P > 0.05$) between FRT for both the Warming treatment (-0.054 °C/min and -0.044 °C/min, respectively) and, also, the Drying+Warming treatment (-0.025 °C/min for both FRT). These results further illustrate that the response to the Intervention Treatments differed between the two FRT.

These results also suggest that the major influence of the warmer FRT was to reduce the extent of the piglet temperature decline in untreated Control pigs; the temperature decline of the other two Intervention Treatments was relatively similar under COOL and WARM FRT. As a consequence, differences between the Control and the Warming and the Drying+Warming treatments for temperature changes after birth were greater ($P \leq 0.05$) under COOL than WARM FRT. For example, the decline in piglet rectal temperature between birth and 30 min for the COOL FRT was 2.8 °C greater ($P \leq 0.05$) for the Control than the Drying+Warming treatment, whereas this difference was 1.7 °C ($P \leq 0.05$) for the WARM FRT (Figure 1). This highlights that, although drying and/or warming of piglets at birth reduced the extent of postnatal temperature decline under both COOL and WARM FRT, this effect was greater under the cooler conditions.

Although a number of studies have evaluated the effects of farrowing room temperature on sow performance (e.g., Black et al., 1993; Koketsu et al., 1996; Muns et al., 2016), there has been limited research with piglets. Le Dividich and Noblet (1981) found that piglets kept in low (18 to 20 °C) compared to high (30 to 32 °C) farrowing pen temperatures had lower rectal temperatures at 20 min after birth (by 1.6 °C). Pedersen et al. (2013) found that piglets in rooms at an ambient temperature of 25 °C had higher rectal temperatures at 30 min after birth (0.9 °C) than those in rooms at temperatures of either 15 or 20 °C. The results of these studies are similar to those for the comparison of FRT reported here, which showed that piglet rectal temperature at 30 min after birth for the Control

treatment was 1.5 °C higher under WARM than COOL FRT (Figure 1).

Subsequent to the decline in rectal temperature in the early postnatal period, temperatures recovered for all treatments, with differences between Intervention Treatments within each FRT decreasing over time (Figure 1). For example, the temperature of Control piglets at 45 min after birth was 1.1 °C greater ($P \leq 0.05$) for WARM compared to COOL FRT; however, this difference was 0.1 °C at 120 min after birth ($P > 0.05$; Figure 1). In addition, the rate of change in piglet rectal temperature between 30 and 1440 min after birth (data not reported) was greater ($P \leq 0.05$) for the Control under COOL (0.024 °C/min) than WARM (0.014 °C/min) FRT. In contrast, for the other two Intervention Treatments the rate of change over this time period, which was lower ($P \leq 0.05$) than for the Control, was the same ($P > 0.05$) at the two FRT (0.001 and 0.0004 °C/min for the Warming and Drying+Warming treatment, respectively).

The rate of recovery in body temperature in newborn piglets after the initial period of temperature decline is determined by the balance between heat loss from and heat production by the animal (Stombaugh et al., 1973). The ambient farrowing room temperatures that the piglets were exposed to remained relatively constant over the two study periods (Table 1; Vande Pol et al., 2021) and, consequently, it is likely that heat loss was relatively constant within FRT and Intervention Treatment. Therefore, recovery from the initial postnatal temperature decline most likely resulted mainly from increases in heat production. The faster rate of temperature recovery for the Control treatment from 30 min after birth suggests that the rate of heat production in this period was considerably higher for piglets on that treatment than for those on the other two Intervention Treatments. However, heat production uses body energy reserves, which are relatively limited in the newborn piglet (Le Dividich et al., 1994, 2005). In addition, energy from ingested colostrum is not immediately available to the piglet for use in heat production (Le Dividich et al., 1994). Consequently, these results also suggest that, although Control piglets were able to recover body temperature relatively quickly, this was likely to be at the expense of relatively high levels of utilization of energy stores, which may have implications for subsequent survival (Declerck et al., 2016).

It should be emphasized that this comparison of FRT is based on the results of two independent studies and, consequently, is not a direct estimate of the effects of FRT *per se*. These two studies were carried out at different times of the same year, and a number of factors other than FRT could have changed in the interim time period that may have influenced the responses of piglets to these Intervention Treatments. However, with the exception of FRT, the differences between the conditions during the two studies were limited. The studies were carried out in the same facilities, involved the same personnel, and used the same measurement equipment and methodology. Further research is needed to directly establish the responses of piglets to drying and warming under differing farrowing room temperatures.

Least-squares means for Intervention Treatment by BWC interactions for piglet rectal temperature within the first 24 h after birth are presented in Table 3. There were interactions ($P \leq 0.05$) at all measurement times except at birth, when rectal temperatures were similar ($P > 0.05$) for all BWC on all Intervention Treatments. At measurement times between 10 and 120 min, Light piglets had lower ($P \leq 0.05$) rectal temperatures than Medium and Heavy piglets for all Intervention Treatments, with the exception of the Drying+Warming treatment at 120 min, when rectal temperatures of Light and Medium piglets were similar ($P > 0.05$; Table 3). Medium piglets had lower ($P \leq 0.05$) rectal temperatures than Heavy piglets between 10 and 120 min for the Control treatment, but only at 10 and 20 min for the other two Intervention Treatments. At other measurement times the rectal temperatures of these two BWC were similar ($P > 0.05$). At 1,440 min, temperature differences between the BWC across the three Intervention Treatments were relatively small (Table 3). A number of studies have also shown that low birth weight piglets experience a greater extent and duration of decline in rectal temperature after birth than heavier littermates (Pattison et al., 1990; Pedersen et al., 2016; Cooper et al., 2019; Vande Pol et al., 2020, 2021).

The difference in rectal temperature between BWC was generally greater for the Control than the other two Intervention Treatments (Table 3). For example, at 60 min after birth for the Control treatment, rectal temperatures of Light piglets were 2.4 and 3.3 °C lower ($P \leq 0.05$) than Medium and Heavy piglets, respectively. In comparison, these differences were 1.3 and 1.5 °C, respectively, for the Warming treatment, and 1.0 and 1.3 °C, respectively, for the Drying+Warming treatment. These results suggest that drying and warming of piglets at birth

Table 3. Least-squares means for the interaction between Intervention Treatment and Birth Weight Category (BWC) on the rectal temperature of piglets over the first 24 h after birth

		Intervention Treatment (IT)[1]				*P*-value
		Control	Warming	Drying+ Warming	SEM	BWC × IT interaction
Number of litters		15	15	15	—	—
Piglet rectal temperature, °C						
Time after birth, min						
0	BWC[2]				0.040	0.31
	Light	38.90	39.01	38.73	—	—
	Medium	39.14	39.21	39.05	—	—
	Heavy	39.16	39.10	39.06	—	—
10	BWC[2]				0.040	<0.0001
	Light	36.24^{g}	36.94^{f}	37.23^{ef}	—	—
	Medium	37.38^{e}	37.90^{cd}	37.99^{bc}	—	—
	Heavy	37.67^{d}	38.22^{ab}	38.37^{a}	—	—
20	BWC[2]				0.040	<0.0001
	Light	35.21^{f}	36.65^{e}	37.32^{cde}	—	—
	Medium	36.73^{e}	37.61^{c}	38.04^{b}	—	—
	Heavy	37.32^{d}	38.07^{ab}	38.39^{a}	—	—
30	BWC[2]				0.040	<0.0001
	Light	34.94^{f}	36.78^{de}	37.52^{cd}	—	—
	Medium	36.65^{e}	37.82^{c}	38.26^{ab}	—	—
	Heavy	37.32^{d}	38.08^{bc}	38.49^{a}	—	—
45	BWC[2]				0.040	<0.0001
	Light	34.62^{f}	36.69^{de}	37.64^{cd}	—	—
	Medium	36.76^{e}	37.81^{c}	38.39^{ab}	—	—
	Heavy	37.63^{c}	38.05^{bc}	38.63^{a}	—	—
60	BWC[2]				0.040	<0.0001
	Light	34.79^{e}	36.73^{d}	37.54^{cd}	—	—
	Medium	37.18^{d}	38.00^{c}	38.58^{ab}	—	—
	Heavy	38.04^{c}	38.25^{bc}	38.80^{a}	—	—
120	BWC[2]				0.041	<0.0001
	Light	35.74^{e}	37.50^{d}	38.05^{bcd}	—	—
	Medium	38.11^{cd}	38.36^{abc}	38.80^{ab}	—	—
	Heavy	38.62^{ab}	38.61^{ab}	38.84^{a}	—	—
1,440	BWC[2]				0.045	0.01
	Light	38.40^{bc}	38.48^{c}	38.68^{abc}	—	—
	Medium	38.78^{c}	39.14^{ab}	38.83^{abc}	—	—
	Heavy	38.84^{abc}	39.11^{a}	38.89^{abc}	—	—

[1]Control = no treatment; Warming = placed in a plastic box under a heat lamp for 30 min; Drying+Warming = dried with desiccant, placed in a plastic box under a heat lamp for 30 min.

[2]Light = <1.0 kg; Medium = 1.0 to 1.5 kg; Heavy = >1.5 kg.

[a,b,c,d,e,f,g]For each time after birth, means within the Intervention Treatment × Birth Weight Category interaction with differing superscripts differ ($P \leq 0.05$).

reduced the variation in postnatal rectal temperature decline due to birth weight. In addition, the magnitude of differences in rectal temperature between the Control and the other treatments was generally greater for Light than for Medium or Heavy piglets (Table 3). For example, at 45 min after birth, the difference in rectal temperature between piglets on the Control and Drying+Warming treatment was 3.0, 1.6, and 1.0 °C for Light, Medium, and Heavy piglets, respectively ($P \leq 0.05$; Table 3). This suggests that drying and warming piglets at birth minimized the extent of postnatal decline in rectal temperature of piglets of all birth weights, but was relatively more effective for lighter piglets.

The limited number of studies that have evaluated the effect of birth weight on the responses to drying and/or warming of piglets at birth have generally shown similar results to the current experiment. Pedersen et al. (2016) found that adding a radiant heat source in the farrowing pen increased

the average piglet rectal temperature in the first 2 h after birth for piglets of all birth weights, but the effect was greater for lighter piglets. Vande Pol et al. (2021) also reported that drying and warming had a relatively greater effect for lighter piglets. However, in that study, the increases in rectal temperature between dried and warmed compared to untreated piglets were greater than in the current study, which, as previously discussed, was most likely due to the difference between these studies in the ambient temperatures in the farrowing rooms.

Least-squares means for the effect of Intervention Treatment and BWC on serum immunoglobulin immunocrit concentrations are presented in Table 4. There were no treatment interactions ($P > 0.05$) for this measurement and, therefore, means for the main effects have been reported. Values for immunocrit concentrations found in the current study, which were in the range of 11.7 to 13.3, were generally within the range of those reported in previous research (Scotten, 2015; Peters et al., 2016; Farmer et al., 2017). Immunocrit concentrations were higher ($P \leq 0.05$) for the Control and Warming treatments compared to the Drying+Warming treatment. It has been shown that serum immunocrit concentration early after birth is an index of colostrum intake (Vallet et al., 2015). On this basis, the results of the current study suggest that drying and warming piglets at birth reduced colostrum intake, however, the cause of this treatment difference is not clear. The piglets on the Drying+Warming were kept in the warming box away from the sow for 30 min after birth, eliminating early suckling; however, the same was true of the piglets on the Warming treatment that had similar immunocrit concentrations to those on the Control treatment. Vallet and Miles (2017) found that piglets from sows that were induced to farrow had lower blood immunocrit concentrations early after birth than those from sows that were not induced. In the current study, the percentage of sows induced to farrow was numerically higher for the Drying+Warming treatment compared to the Control and Warming treatments (34.9, 27.9, and 23.1%, respectively). However, it is unclear to what extent this difference contributed to treatment differences in piglet serum immunocrit concentrations. There were no other studies found that evaluated the effects of drying or warming piglets at birth on immunocrit concentration.

There was a trend ($P = 0.10$) for immunocrit values to be greater for Heavy compared to Light or Medium BWC piglets, suggesting that lighter birth weight piglets consumed less colostrum than heavier littermates. This is in line with the results of other studies that have evaluated the impact of birth weight on immunocrit concentrations (Devillers et al., 2011; Nguyen et al., 2013; Vallet et al., 2013; Le Dividich et al., 2017) and also with those that have directly measured the impact of birth weight on colostrum intake (Devillers et al., 2011; Le Dividich et al., 2017).

In conclusion, the results of the current study confirm that piglet birth weight is an important factor influencing postnatal rectal temperature, with lower birth weight piglets experiencing the greatest extent and duration of temperature decline. Warming piglets at birth was effective at reducing piglet rectal temperature decline in the early postnatal period, with the combination of drying and warming being more effective, especially for low birth weight piglets. The lower response in piglet postnatal rectal temperature to drying and/

Table 4. Least-squares means for the effect of Intervention Treatment and Birth Weight Category on immunoglobulin immunocrit values at 24 h after birth

	Intervention Treatment[1]					Birth Weight Category[2]				
Item.	Control	Warming	Drying+ Warming	SEM	*P*-value	Light	Medium	Heavy	SEM	*P*-value
Number of piglets	54	56	55	—	—	15	80	70	—	—
Birth weight, kg	1.44	1.47	1.45	0.055	0.93	0.88	1.31	1.75	0.027	<0.0001
Immunoglobulin immunocrit, %[3]	13.1[a]	13.2[a]	11.7[b]	0.42	0.03	12.0	12.3	13.3	0.51	0.10

[1]Control = no treatment; Warming = placed in a plastic box under a heat lamp for 30 min; Drying+Warming = dried with desiccant, placed in a plastic box under a heat lamp for 30 min.

[2]Light = <1.0 kg; Medium = 1.0 to 1.5 kg; Heavy = >1.5 kg.

[3]Blood samples obtained at 24 h after birth on a subsample of four piglets per litter, one from each birth weight quartile.

or warming observed in this experiment compared to previous studies may be related to the higher farrowing room temperatures experienced during the conduct of this study; however, further research is required to validate this concept.

ACKNOWLEDGMENTS

Funding, wholly or in part, was provided by the National Pork Checkoff. Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture. The U.S. Department of Agriculture (USDA) prohibits discrimination in all its programs and activities on the basis of race, color, national origin, age, disability, and where applicable, sex, marital status, familial status, parental status, religion, sexual orientation, genetic information, political beliefs, reprisal, or because all or part of an individual's income is derived from any public assistance program. (Not all prohibited bases apply to all programs.) Persons with disabilities who require alternative means for communication of program information (Braille, large print, audiotape, etc.) should contact USDA's TARGET Center at (202) 720-2600 (voice and TDD). To file a complaint of discrimination, write to USDA, Director, Office of Civil Rights, 1400 Independence Avenue, S.W., Washington, DC 20250-9410, or call (800) 795-3272 (voice) or (202) 720-6382 (TDD). USDA is an equal opportunity provider and employer.

LITERATURE CITED

Andersen, H. M., and L. J. Pedersen. 2015. Effect of radiant heat at the birth site in farrowing crates on hypothermia and behaviour in neonatal piglets. Animal. 10:128–134. doi:10.1017/S1751731115001913

Berbigier, P., J. Le Dividich, and A. Kobilinsky. 1978. Echanges thermiques chez le porcelet nouveau-né: application de la méthode du bilan d'énergie. Ann. Zootech. 27:181–194. doi:10.1051/animres:19780206

Black, J. L., B. P. Mullan, M. L. Lorschy, and L. R. Giles. 1993. Lactation in the sow during heat stress. Livest. Prod. Sci. 35:153–170. doi:10.1016/0301-6226(93)90188-N

Christison, G. I., I. I. Wenger, and M. E. Follensbee. 1997. Teat seeking success of newborn piglets after drying or warming. Can. J. Anim. Sci. 77:317–319. doi:10.4141/A96-119

Cooper, N.C, K. D. Vande Pol, M. Ellis, Y. Xiong, and R. Gates. 2019. Effect of piglet birth weight and drying on post-natal changes in rectal temperature. Proc. Midw. Anim. Sci. Meet. 97:4. doi:10.1093/jas/skz122.006

Declerck, I., J. Dewulf, R. Decaluwe, and D. Maes. 2016. Effects of energy supplementation to neonatal (very) low birth weight piglets on mortality, weaning weight, daily weight gain and colostrum intake. Livest. Sci. 183:48–53. doi:10.1016/j.livsci.2015.11.015

Devillers, N., J. Le Dividich, and A. Prunier. 2011. Influence of colostrum intake on piglet survival and immunity. Animal. 5:1605–1612. doi:10.1017/S175173111100067X

Farmer, C., M. Lessard, C. H. Knight, and H. Quesnel. 2017. Oxytocin injections in the postpartal period affect mammary tight junctions in sows. J. Anim. Sci. 95:3532–3539. doi:10.2527/jas.2017.1700

Herpin, P., M. Damon, and J. Le Dividich. 2002. Development of thermoregulation and neonatal survival in pigs. Livest. Prod. Sci. 78:25–45. doi:10.1016/S0301-6226(02)00183-5

Houbak, B., K. Thodberg, J. Malkvist, and L. J. Pedersen. 2006. Effect of pen floor heating on piglets use of heated area 0–120 h postpartum. In: M. Mendl, J. W. S. Bradshaw, O. H. P. Burman, A. Butterworth, M. J. Harris, S. D. E. Held, S. M. Jones, K. E. Littin, D. C. J. Main, C. J. Nicol, R. M. A. Parker, E. S. Paul, G. Richards, C. M. Sherwin, P. T. E. Statham, M. J. Toscano, and P. D. Warriss, editors. Proceedings of the 40th International Congress of the ISAE, 156. Bristol, United Kingdom, August 2006. Edinburgh (UK): International Society for Applied Ethology.

Kammersgaard, T. S., L. J. Pedersen, and E. Jørgensen. 2011. Hypothermia in neonatal piglets: interactions and causes of individual differences. J. Anim. Sci. 89:2073–2085. doi:10.2527/jas.2010-3022

Koketsu, Y., G. D. Dial, J. E. Pettigrew, W. E. Marsh, and V. L. King. 1996. Characterization of feed intake patterns during lactation in commercial swine herds. J. Anim. Sci. 74:1202–1210. doi:10.2527/1996.7461202x

Le Dividich, J., R. Charneca, and F. Thomas. 2017. Relationship between birth order, birth weight, colostrum intake, acquisition of passive immunity and pre-weaning mortality of piglets. Span. J. Agric. Res. 15:e0603. doi:10.5424/sjar/2017152-9921

Le Dividich, J., P. Herpin, and R. M. Rosario-Ludovino. 1994. Utilization of colostral energy by the newborn pig. J. Anim. Sci. 72:2082–2089. doi:10.2527/1994.7282082x

Le Dividich, J., and J. Noblet. 1981. Colostrum intake and thermoregulation in the neonatal pig in relation to environmental temperature. Biol. Neonate 40:167–174. doi:10.1159/000241486

Le Dividich, J., J. A. Rooke, and P. Herpin. 2005. Nutritional and immunological importance of colostrum for the new-born pig. J. Agric. Sci. 143:469–485. doi: 10.1017/S0021859605005642

Littell, R. C., G. A. Milliken, W. W. Stroup, and R. D. Wolfinger. 1996. SAS systems for mixed models. Cary (NC): SAS Inst. Inc.

Littledike, E.T., D. A. Witzel, and J. L. Riley. 1979. Body temperature changes in sows during the periparturient period. Lab. Anim. Sci. 29:621–624.

McGinnis, R. M., D. N. Marple, V. K. Ganjam, T. J. Prince, and J. F. Pritchett. 1981. The effects of floor temperature, supplemental heat and drying at birth on neonatal swine. J. Anim. Sci. 53:1424–1432. doi:10.2527/jas1982.5361424x

Mount, L. E. 1959. The metabolic rate of the new-born pig in relation to environmental temperature and age. J. Physiol. 147:333–345. doi:10.1113/jphysiol.1959.sp006247

Muns, R., J. Malmkvist, M. L. Larsen, D. Sørensen, and L. J. Pedersen. 2016. High environmental temperature around farrowing induced heat stress in crated sows. J. Anim. Sci. 94:377–384. doi:10.2527/jas.2015-9623

Nguyen, K., G. Cassar, R. M. Friendship, C. Dewey, A. Farzan, R. N. Kirkwood, and D. Hodgins. 2013. An investigation of the impacts of induced parturition, birth weight, birth order, litter size, and sow parity on piglet serum concentrations of immunoglobulin G. J. Swine Health Prod. 21:139–143.

Pattison, R., P. English, O. MacPherson, J. Roden, and M. Birnie. 1990. Hypothermia and its attempted control in newborn piglets. Proc. Br. Soc. Anim. Prod. 1990:81–81. doi:10.1017/S0308229600018626

Pedersen, L. J., E. Jorgensen, T. Heiskanen, and B. I. Damm. 2006. Early piglet mortality in loose-housed sows related to sow and piglet behaviour and to the progress of parturition. App. Anim. Behav. Sci. 96: 215–232. doi:10.1016/j.applanim.2005.06.016

Pedersen, L. J., M. L. Larsen, and J. Malmkvist. 2016. The ability of different thermal aids to reduce hypothermia in neonatal piglets. J. Anim. Sci. 94:2151–2159. doi:10.2527/jas.2015-0219

Pedersen, L. J., J. Malmkvist, T. Kammersgaard, and E. Jørgensen. 2013. Avoiding hypothermia in neonatal pigs: effect of duration of floor heating at different room temperatures. J. Anim. Sci. 91:425–432. doi:10.2527/jas.2011-4534

Peters, B. M., S. A. Krantz, D. J. Holtkamp, C. Wang, and L. G. Pantoja. 2016. Reference values for immunocrit ratios to assess maternal antibody uptake in 1-day-old piglets. J. Swine Health Prod. 24:36–41.

PIC. 2018. Farrowing room preparation. https://www.pic.com/wp-content/uploads/sites/3/2018/12/11.20.18-Farrowing-Room-Preparation.pdf. Accessed June 11, 2020.

PigChamp. 2018. Benchmarking summaries. www.pigchamp.com/benchmarking. Accessed June 11, 2020.

Pomeroy, R. W. 1953. Studies on piglet mortality. I. Effect of low temperature and low plane of nutrition on the rectal temperature of the young pig. J. Agric. Sci. 43:182–191. doi:10.1017/S0021859600044956

Scotten, S. S. 2015. Effect of colostrum supplementation on baby pig performance [master's thesis]. Manhattan (KS): Kansas St. University.

Stombaugh, D. P., W. L. Roller, T. Adams, and H. S. Teague. 1973. Temperature regulation in neonatal piglets during mild cold and severe heat stress. Am. J. Physiol. 225:1192–1198. doi:10.1152/ajplegacy.1973.225.5.1192

Vallet, J. L., J. R. Miles, and L. A. Rempel. 2013. A simple novel measure of passive transfer of maternal immunoglobulin is predictive of preweaning mortality in piglets. Vet. J. 195:91–97. doi:10.1016/j.tvjl.2012.06.009

Vallet, J. L., J. R. Miller, L. A. Rempel, D. J. Nonneman, and C. A. Lents. 2015. Relationship between day one piglet immunoglobulin immunocrit and subsequent growth, puberty attainment, litter size, and lactation performance. J. Anim. Sci. 93:2722–2729. doi:10.2527/jas.2014–8535

Vallet, J. L., and J. R. Miles. 2017. The effect of farrowing induction on colostrum and piglet serum immunocrits is dependent on parity. J. Anim. Sci. 95:688–696. doi:10.2527/jas.2016.0993

Vande Pol, K. D., A. F. Tolosa, C. M. Shull, C. B. Brown, S. A. S. Alencar, and M. Ellis. 2020. Effect of method of drying piglets at birth on rectal temperature over the first 24 h after birth. Transl. Anim. Sci. 4:1–12. doi:10.1093/tas/txaa183

Vande Pol, K. D., A. F. Tolosa, C. M. Shull, C. B. Brown, S. A. S. Alencar, and M. Ellis. 2021. Effect of drying and/or warming piglets at birth on rectal temperature over the first 24 h after birth. Transl. Anim. Sci. 4:txaa184. doi:10.1093/tas/txaa184

Vasdal, G., I. Ostensen, M. Melisova, B. Bozdechova, G. Illmann, and I. L. Andersen. 2011. Management routines at the time of farrowing-effects on teat success and postnatal piglet mortality from loose housed sows. Livest. Sci. 136:225–231. doi:10.1016/j.livsci.2010.09.012

Xiong, Y., R. Gates, N. Cooper, and M. Ellis. 2018. Neonatal piglet core body temperatures model from surface temperature and environment measurements. In G. Fox, editor. Proceedings of the International Livestock Environment Symposium. Omaha, NE, 2018. S. Joseph (MI): American Society of Agricultural and Biological Engineers; p. 1–12. doi:10.13031/iles.18–128

Zotti, E., F. A. Resmini, L. G. Schutz, N. Volz, R. P. Milani, A. M. Bridi, A. A. Alfieri, and C. A. da Silva. 2017. Impact of piglet birthweight and sow parity on mortality rates, growth performance, and carcass traits in pigs. R. Bras. Zootec. 46:856–862. doi:10.1590/s1806-92902017001100004