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Effects of negative pressure and directed ducted cooling systems on the performance of lactating sows

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ABSTRACT - The objective of the present study was to evaluate the effects of cooling systems by negative pressure versus directed ducts on the performance of lactating sows and their litter. The experiment was conducted in a tropical climatic region in Brazil. Ninety-four lactating sows during 26.2±1.7 days of lactation were included with their 1,236 piglets. Sows were distributed using a completely randomized block design into two treatments: a negative pressure cooling (NPC) system and a directed duct cooling (DDC) system. We adopted sow parity as blocking criterion. During the experimental period, environmental temperatures inside the farrowing rooms were 22.9±1.5 and 25.4±2.5 °C, respectively, using the NPC and DDC systems. Sow daily feed intake, litter weight at weaning, piglet weight at weaning, litter daily weight gain, piglet daily gain, and daily milk production per sow were greater in the NPC system than in the DDC system. The type of cooling system did not affect piglet weight after standardization, mortality, number of piglets weaned per sow, and estrus return. The use of an NPC system can reduce the effects of higher environmental temperatures better than the DDC system. The NPC system allowed for greater feed intake, piglet and litter weight gain, weight of piglets and litter at weaning, and milk production compared with the DDC system.

Keywords: biometeorology, lactation, milk production, thermoregulation, weaning

1. Introduction

When the effective environmental temperature increases above the thermoneutral temperature (15 to 25 °C, Ribeiro et al., 2018), animals use behavioral, physical, and biochemical mechanisms that can reduce the energy available for production, which modifies their nutrient requirements and performance (Kyriazakis and Whittemore, 2006; Oliveira et al., 2019). Lactating sows are particularly susceptible to increased environmental temperature due to the high heat production resulting from the metabolic activity required for milk production (Renaudeau and Noblet, 2001; Renaudeau et al., 2003).

In high ambient temperatures (30 °C), lactating sows experience shallow breathing and increased respiratory rate and water intake in an attempt to maintain homeothermia (De Bragança et al., 1998). Heat-stressed sows show a reduction in feed intake and milk production, consequently resulting in a reduction of piglet growth (Kiefer et al., 2012) and increase of non-productive days. Moreover, continuous exposure to high ambient temperatures will adversely affect estrous behavior and may also lead to reduced conception rate and increased embryonic mortality (Renaudeau et al., 2003). Previous studies have suggested that the implementation of cooling strategies is crucial to improve reproductive and productive sow performance under tropical conditions (Renaudeau et al., 2003; Kiefer et al., 2012; Chen et al., 2018).

Cooling systems can be considered efficient alternatives to minimize the adverse effects of high air temperatures on the performance of lactating sows, and pig producers may opt to build barns using different technologies. Previously, our group demonstrated that negative pressure cooling system attenuates the environmental temperature, increasing sow and piglet performance in the farrowing room compared with the one with the conventional system (Kiefer et al., 2012). Recently, the use of directed duct systems has been adopted by the pig industry to improve the performance of the lactating sows (Perin et al., 2016). Both studies compared their respective cooling system against the conventional system. However, the information comparing negative pressure against the duct cooling system is lacking. There is a hypothesis that the evaporative system can provide better results. In this context, the objective of the present study was to evaluate the effects of cooling systems by negative pressure versus directed ducts on the performance of lactating sows and their litter.

2. Material and Methods

The experiment was conducted during the fall season from March to April in a commercial farm in São Gabriel do Oeste, MS, Brazil (19°23'43" S, 54°33'59" W), located in a tropical climatic region. The research was previously approved by the Institutional Ethics Committee on Animal Use (number 958/2018).

2.1. Animals, experimental design, and housing

Ninety-four lactating sows (Camborough PIC) with 3.25±1.79 sow parity during 26.2±1.7 days of lactation were included with their 1236 piglets. Sows were distributed using a completely randomized block design into two treatments: the negative pressure cooling (NPC) system and directed duct cooling (DDC) system, with 55 repetitions for the NPC system and 39 repetitions for the DDC system, in which each sow was considered a repetition. We adopted sow parity as blocking criterion. Three blocks were designed (block I: 1 and 2 farrowing order; block II: between 3 and 5 farrowing orders; block III: 6 or higher farrowing order).

In both systems, animals were housed in similar farrowing rooms of 7 m wide, 117 m long, and 3 m high, with cast plastic flooring and a yellow curtain lining. Sows were individually housed in a cage with a farrowing crate (0.6 × 2.2 m) and lateral areas (0.3 × 2.2 m) exclusive to piglets. Each cage was equipped with a semiautomatic feeder and a shell drinker for sows. Piglets had free access to a juggler and a heated concrete floor.

2.2. Cooling system and thermal environment

The NPC system consisted of evaporative plates and eight exhaust fans of 50 inches each. The system was controlled by an electronic panel installed inside the room, regulated to a temperature of 22 °C. The system has a fan that draws external air through a special evaporative panel through which the water continually flows through a small pump. The water that evaporates is replaced by a buoy that keeps the constant level in the reservoir. After being cooled by the system, the air is canalized through ducts positioned on the cervical region of the matrices. The cooling system was shortly activated after the sows entered the farrowing room, remaining in operation 24 h a day throughout the experimental period, and the curtains system was not used.

The DDC system was similar to that in Perin et al. (2016), with slight modifications. Briefly, the DDC system operated utilizing adiabatic evaporative plates located at the end of the rooms that was channeled through plastic canvas ducts (250 cm long and 20 cm of diameter) directed to the sows, in the anterior part of the cage. The cooled air from the evaporative plate was pushed through an axial fan into the duct and thus led to the females in the farrowing rooms. The activation of the system was controlled by a panel inside the room, without a thermostat. The system was kept active throughout the sows housing period until weaning, except for the interval between 1:00 and 6:00 h. The curtain system was used in association with the DDC system.

2.3. Management

During gestation, all sows were subjected to the same handling and nutrition procedures. Sows were transferred to one of the two farrowing rooms five days before the expected farrowing date. Sows and piglets had free access to water through bite nipple drinkers. The cages were equipped with semi-automatic feeders for sows and conventional feeders for piglets.

Until the farrowing day, a lactation diet (Table 1) was offered daily in the amount of 2.0 kg/day, at 08:00 and 15:00 h. After birth, nutritional management consisted of a two-day restraint period with a supply of 2.0 kg/day. From the third day until weaning, each female received feed *ad libitum*. From the sixth day of age, piglets were fed 0.25 kg/day for each litter.

Table 1 - Ingredient and analyzed chemical composition of diets (as-fed basis)

Ingredient	g/kg
Corn	679.3
Soybean meal (46.0%)	241.0
Soybean oil	39.0
Concentrate[1]	14.0
Salt	6.0
Limestone	4.4
Dicalcium phosphate	12.1
Adsorbent	1.0
Sodium bicarbonate	3.0
Antibiotic	0.2
Analyzed composition (g/kg)	
Crude protein	175.0
Crude fat	69.1
Crude fiber	27.2
Mineral matter	45.7
Total calcium	8.90
Total phosphorus	5.49
Available phosphorus	4.45
Metabolizable energy (Mcal/kg)	3.40
Total lysine	12.52
Total met + cis	6.51
Total threonine	7.90
Total tryptophan	2.09
Sodium	2.15

[1] Content per kg of product: calcium, 15 mg; phosphorus, 460 mg; lysine, 240 g; methionine, 40 g; copper, 2,857 mg; chromium, 17 mg; iron, 7,428 mg; iodine, 57 mg; manganese, 3,428 mg; selenium, 18 mg; zinc, 9,142 mg; vitamin A, 857,142 IU; vitamin D3, 114,285 IU; vitamin E, 4,571 IU; vitamin K3, 114 mg; vitamin B1, 85 mg; vitamin B2, 514 mg; vitamin B6, 214 mg; vitamin B12, 1,714 mcg; niacin, 2,285 mg; pantothenic acid, 1,142 mg; folic acid, 200 mg; biotin, 74 mg; choline, 25 g; phytase, 28 U/g; xylanase, 62 U/g; glucanase, 5 U/g; protease, 857 U/g.

2.4. Response variables

The sow daily feed intake was determined by the difference between the offered and the leftovers, daily collected, before the first feeding in the morning. Litters were standardized in the first 24 h after birth with 13.2 piglets per female. Piglets were individually weighed after birth, after standardization, and at weaning to estimate piglet and litter weight at weaning, piglet weight after standardization, and daily piglet and litter weight gain. Number of piglets weaned per sow, mortality per litter, and mortality percentage and sow estrus return were also recorded.

Daily milk production was estimated according to the equation proposed by Ferreira et al. (1988): milk production (kg/day) = [(4.27 × piglet weight gain in the period {kg}) × number of piglets] / number of days of lactation.

The thermal environment inside the farrowing rooms was monitored twice a day (7:30 and 15:30 h) using minimum and maximum (analog thermometer, Zürich, Brazil) and black-globe thermometer (WBGT8778, Akso, Brazil) installed at the center of the rooms. The thermometers were installed at the average height of the animals. These data were then converted to the black globe humidity index (BGHI) to characterize the thermal ambient of the sows, according to Buffington et al. (1981).

2.5. Statistical analysis

The experimental data were analyzed in a randomized block design in which the cooling system was the treatment and sow paritywas considered as a block. The Shapiro-Wilk test was used to assess the normal distribution of data prior to final analyses, as appropriate. Results were considered statistically significant when P<0.05. Analyses were performed using the general linear procedure analysis of variance (GLM procedure) of SAS (Statistical Analysis System, version 9.1). The least square means procedure (PDIFF option) was used to compare means when a significant F-value was obtained. Data were analyzed using the following model:

$$y_{ijk} = \mu + T_i + \beta_j + e_{ijk},$$

in which y_{ijk} is the observed variable of the k-th animal in the i-th treatment and j-th block; μ is the overall mean; T_i is the fixed-effect of the i-th treatment; β_j is the fixed effect of the j-th block effect; and e_{ijk} is the random residual associated with y_{ijk}, assuming $e_{ijk} \sim (0, \sigma_e^2)$. Weight and number of piglets in the litter, after equalization, were used as covariates when significant (P<0.05).

Sow daily feed intake was subjected to regression analysis to test the effects of the cooling system over feed intake during lactation. In this case, data were analyzed using the following model:

$$y_{ij} = \beta_0 + \beta_1 x_i + \beta_2 x_i^2 + e_{ij},$$

in which y_{ij} is the observed variable; β_0, β_1, and β_2 are regression coefficients; x_i is the fixed effect; and e_{ij} is the random residual error.

3. Results

During the experimental period, environmental temperatures inside the farrowing rooms were 22.9±1.5 and 25.4±2.5 °C, respectively, using the NPC and DDC systems. Relative air humidity was 90.5±6.3 and 81.0±6.7%, respectively, using NPC and DDC, and BGHI was 72.5±1.4 and 75.2±2.6, respectively.

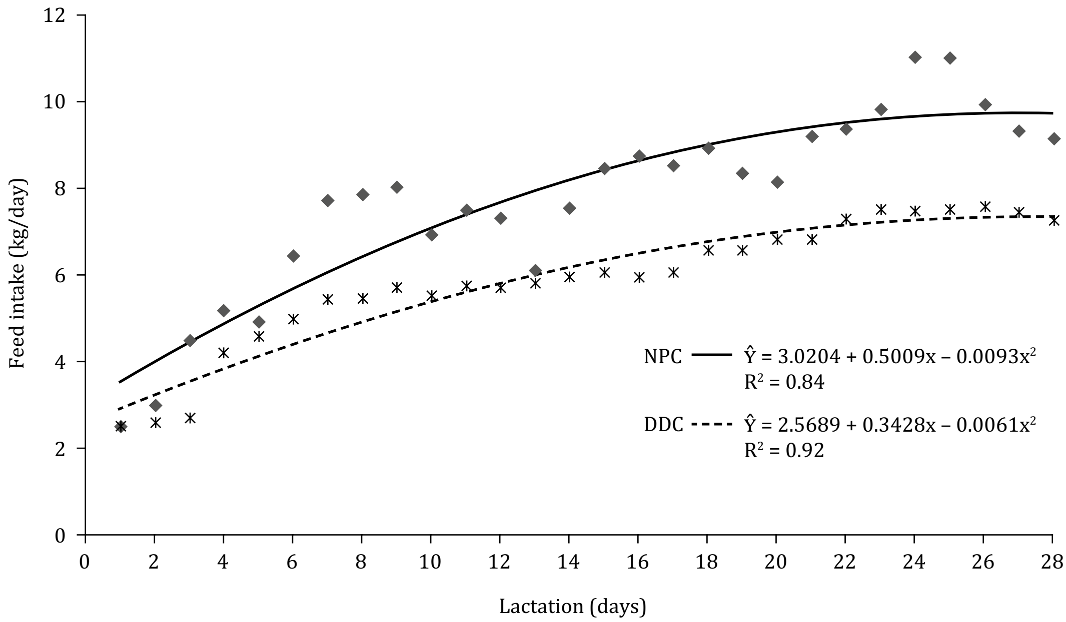
Sow daily feed intake (P<0.001), litter weight at weaning (P<0.001), piglet weight at weaning (P<0.001), litter daily weight gain (P<0.001), piglet daily gain (P<0.001), and daily milk production (P<0.001) per sow were greater in the NPC than in the DDC system (Table 2). Type of cooling system did not affect piglet weight after standardization (P = 0.109), mortality (P = 0.216), number of piglets weaned per sow (P = 0.216), and estrus return (P = 0.836).

The analysis of the intake pattern of sows (Figure 1) showed that both groups presented quadratic (P<0.001) responses in relation to daily feed intake during the lactation period.

Table 2 - Performance of sows and their litters according to cooling systems[1]

Item	NPC	DDC	SEM	P-value
Number of sows	55	39	-	-
Sow parity	3.0	3.4	-	-
Days of lactation	26.71	25.61	-	-
Number of piglets	12.87	13.53	1.223	-
Initial litter weight (kg)	20.87	19.74	4.733	-
Sow daily feed intake (kg)	7.52	5.75	0.727	<0.001
Piglet weight after standardization (kg)	1.56	1.53	0.078	0.109
Litter weight at weaning (kg)	88.57	70.29	13.220	0.001
Piglet weight at weaning (kg)	7.42	6.06	1.005	<0.001
Litter daily weight gain (kg)	2.56	1.95	0.516	<0.001
Piglet daily weight (g)	219	178	0.039	<0.001
Mortality of piglets per litter	1.17	1.53	1.318	0.216
Mortality (%)	8.52	11.47	9.947	0.180
Number of piglets weaned per sow	11.98	11.61	1.318	0.216
Daily milk production per sow (kg)	10.23	7.80	2.063	<0.001
Estrus return (days)	3.87	3.92	0.112	0.836

SEM - standard error of the mean.
[1] NPC - negative pressure cooling system; DDC - directed duct cooling system.



NPC - negative pressure cooling system; DDC - directed duct cooling system.

Figure 1 - Daily feed intake pattern of sows according to the cooling system.

4. Discussion

When ambient temperature rises above 25 °C, lactating sows can be considered to be under heat stress (Ribeiro et al., 2018); under the tropical climatic conditions in Brazil, the average temperatures frequently exceeded 25 °C. Therefore, without any kind of cooling system, lactating sows had been suffering from heat stress most of the time in farrowing rooms. In the present study, we evaluated the influence of two different types of cooling systems, NPC and DDC, in the performance of lactating sows.

The NPC system, versus the DDC system, provided a reduction of the ambient temperature (22.9±1.5 vs. 25.4±2.5 °C). Considering that, the thermal comfort zone for lactating sows is characterized by temperatures varying between 16 and 22 °C (Black et al., 1993; De Bragança et al., 1998), and based on the environmental thermal deviations observed during the experimental period, it can be concluded that the sows in rooms employing the NPC system were subjected to temperatures ranging from the upper limit of the comfort zone to moderate heat temperatures. On the other hand, the temperatures recorded in rooms using the DDC system indicated that sows were above the comfort zone most of the time. The observed average BGHI was 72.5 in the NPC system and 75.2 in the DDC system. According to Turco et al. (1998) and Oliveira Júnior et al. (2011), the comfort zone for lactating sows is characterized by a BGHI value lower than 72; thus, the sows in the NPC room were closer to the thermal comfort zone.

By analyzing the average results and the deviations for the relative humidity of the air, we can infer that both systems presented values (90.5±6.3% in NPC and 81.0±6.7% in DDC) higher than the range established in the literature for thermal comfort environments for lactating sows (from 45.0 to 83.1%; Ribeiro et al., 2018). Environments with high relative humidity can further impair the feed intake of lactating sows when associated with high ambient temperatures (Gourdine et al., 2004). The explanation is that, in pigs, evaporative heat loss due to increased respiratory rate is limited when the relative humidity of the air is high (Renaudeau, 2005). However, we can infer that in the NPC system, with very high relative humidity values, which is one of the characteristics of this system and superior to the DDC system, the relative humidity of the air was beneficial for providing thermal comfort to lactating sows.

When comparing the daily feed intake pattern of sows, both groups demonstrated a quadratic pattern over the lactation period. However, sows under NPC system showed an increase in daily feed intake of approximately 25% compared with the group under DDC system. Moreover, sows under NPC system had a higher feed intake pattern from the beginning to the end of lactation, wherein the difference was more pronounced at the end of the experimental period, in which the peak of feed intake was 9.9 and 7.4 kg per day for sows subjected to NPC and DDC system, respectively.

The highest daily feed intake observed for sows kept in the NPC room could be explained by the association of three factors: reduction of effective ambient temperature (2.5 °C), increase of relative humidity (9.5%), and displacement of mass of air provided by the negative pressure system. The interaction of these bioclimatic elements provided a reduction of 2.7 in the BGHI and, thus, may have resulted in the improvement of sensible avenues of heat loss to the environment, allowing a thermal condition closer to the sows' comfort zone. The increase in sow feed intake due to the use of cooling systems has been observed in previous studies (Kiefer et al., 2012; Perin et al., 2016; Chen et al., 2018).

The optimization of daily feed intake of lactating sows is critical since it is related to the increase in milk production capacity (Quiniou and Noblet, 1999). In fact, in the present study, the 25% increase in daily feed intake of sows under NPC system resulted in a 25% proportional increase in daily milk production and, consequently, an increase in piglet and litter weight gain. The observed increase in feed intake, milk production, piglet weight gain, and weaning weight while using NPC may reflect the superiority of this cooling system relative to DDC.

De Bragança et al. (1998) showed that the reduction of nutrient availability due to low feed intake leads to a decrease in milk production, and the ability of lactating females to mobilize and redistribute nutrients from the reserve tissues is impaired under high-temperature conditions either by endocrine changes and/or blood flow. Furthermore, Renaudeau et al. (2003), under some conditions (20 vs. 28 °C), observed a reduction in breast arterial flow, confirming the existence of cardiovascular adjustments as responses to elevated environmental temperatures.

Similarly, Ribeiro et al. (2018), in a meta-analytic study, found that for every 1 °C increase in ambient temperature above thermal comfort (25 °C), there is a reduction in feed intake, milk production, and piglet weight at weaning. Silva et al. (2021) confirmed that under tropical conditions, high ambient temperatures (26.2 °C) have an impact on performance, voluntary feed intake, and feeding behavior of lactating sows.

The greater weaning weight of piglets and litter from sows under the NPC system is associated with sow daily feed intake and increase in milk production. Renaudeau et al. (2003) and Kiefer et al. (2012) also associated the greater performance of piglets from sows under the cooling system with sow daily feed intake and increase in milk production.

In the present study, the piglet mortality rate during lactation was not affected by treatments. This fact might indicate that environmental temperature differences between systems were not enough to induce a higher frequency of the behavior of body position change. According to Martins et al. (2008), sows under heat stress present higher frequencies of lateral and lying movements in the lactating phase, and these behavioral changes likely explain the increase in mortality related to thermal discomfort.

The weaning index did not differ between the studied cooling systems, a fact that could probably be explained by the favorable general metabolic status of the sows after weaning, and the mobilization of corporal tissues in the lactation period was not enough to affect the beginning of the next reproductive cycle, which was also evidenced by Renaudeau et al. (2003). Kiefer et al. (2012) and Perin et al. (2016) demonstrated that negative pressure and duct cooling system both improve lactating sows and their piglets' performance compared with the conventional system. The present study compared both systems and found that the NPC system is better at reducing heat stress than the DDC system.

5. Conclusions

The use of a negative pressure cooling system can reduce the effects of higher environmental temperatures better than the directed duct cooling system. Moreover, the negative pressure cooling system allows a greater feed intake, piglets and litter weight gain, weight of piglets and litter at weaning, and milk production compared with the directed duct cooling system.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Investigation: A.M.P.S. Silva, C. Kiefer, K.M.R.S. Nascimento, A. Corassa, D.M. Sarturi, S.A.S. Alencar, T.V.A. Farias and G.C. Rocha. Methodology: A.M.P.S. Silva, C. Kiefer, K.M.R.S. Nascimento, A. Corassa, D.M. Sarturi, S.A.S. Alencar, T.V.A. Farias and G.C. Rocha. Supervision: C. Kiefer. Writing-original draft: A.M.P.S. Silva. Writing-review & editing: A.M.P.S. Silva, C. Kiefer, K.M.R.S. Nascimento, A. Corassa, S.A.S. Alencar, T.V.A. Farias, M.S. Gomes and G.C. Rocha.

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