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Rectal Temperature of Lactating Sows in a Tropical Humid Climate according to Breed, Parity and Season

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ABSTRACT : The effects of season (hot vs. warm) in a tropical humid climate, parity (primiparous vs. multiparous) and breed (Creole: CR, Large White: LW) on rectal temperature (RT) were studied for a total of 222 lactations obtained in 85 sows (43 CR and 42 LW; 56 primiparous and 166 multiparous) over a 28-d lactation, between June 2002 and April 2005. Mean daily ambient temperature was higher during the hot season than during the warm season (26.0 vs. 24.1°C) and relative humidity was high and similar in both seasons (89% on average). At farrowing, BW was lower (172 vs. 233 kg) and backfat thickness was higher (37 vs. 21 mm) in CR than in LW sows ($p<0.01$). During the hot season, the reduction of average daily feed intake (ADFI) was more pronounced in LW than in CR sows (-920 vs. -480 g/d, $p<0.05$). Rectal temperature was higher at 1200 than at 0700hr, which coincides with the maximum and the minimum values of daily ambient temperature. The daily RT increased (+0.9°C; $p<0.01$) between d -3 and d 7 (d 0: farrowing day), remained constant between d 7 and d 25 and decreased ($p<0.01$) thereafter (i.e. -0.6°C between d 25 and d 32). The average daily RT was significantly higher during the hot than during the warm season (38.9 vs. 38.6°C; $p<0.01$). It was not affected by breed, but the difference in RT between the hot and warm seasons was more pronounced in LW than in CR sows (+0.4 vs. +0.2°C; $p<0.05$). Parity influenced the RT response; it was greater in primiparous than in multiparous sows (38.9 vs. 38.7°C; $p<0.01$). This study suggests that thermoregulatory responses to heat stress can differ between breeds and between parities. (**Key Words** : Rectal Temperature, Thermoregulation, Sows, Breed, Parity, Tropical Climate)

INTRODUCTION

It is well established that performance of sows in hot conditions depends on their ability to maintain thermal balance (Makkink and Schrama, 1998). Like other homeothermic animals, pigs have to regulate body temperature by maintaining a balance between heat production and heat loss. According to its high nutrient requirement, the lactating sow is particularly sensitive to high ambient temperature. When ambient temperature increases above the thermoneutral zone (between 12 and 20°C, Black et al., 1993), homeothermy is maintained by a modification in the posture and an increase in skin blood flow. With further increase in temperature above the evaporative critical temperature (i.e. >20°C), homeothermy is maintained by an increase in evaporative heat loss and by a decrease in metabolic heat production via a reduction of voluntary feed intake (VFI) (as reviewed by Renaudeau, 2001). This reduced VFI has negative consequences on body reserves mobilization, milk production and more generally on sow longevity (Dourmad et al., 1994). These problems occur in (sub)tropical countries but also in temperate countries during summer temperature peaks and therefore they can reduce the economic gain in animal production. Moreover, an increase in rectal temperature (RT) is reported in the literature when sows are exposed to experimental temperature higher than 25°C (Quiniou and Noblet, 1999). In other words, when temperature exceeds 25°C, the pathways implicated in body temperature regulation are saturated or insufficient to prevent an increase in RT. Interpretations have often been based on the assumptions that RT is the result of the entire thermoregulation process and therefore quantification of RT has been used to characterize the body ability to maintain

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the thermal balance in beef cattle (Amakiri and Funsho, 1979; Turner, 1982) and in pig (Renaudeau, 2005; Huynh, 2005). Surprisingly, little has been published on the influence of animal related factors on RT in lactating sows and on variation of these responses with seasonal and diurnal changes encountered in tropical conditions. The objective of this study was to investigate effects of season and parity on RT of Large White and Creole sows reared in a tropical humid climate.

MATERIALS AND METHODS

Animal management

A total of 222 lactations on 85 sows (43 Creole and 42 Large White sows) divided in 20 successive groups of nine to 11 animals were used in a trial conducted at the INRA experimental facilities in Guadeloupe, French West Indies (Latitude 16°N, Longitude 61°W); this area is characterized by a tropical humid climate (Berbigier, 1988). The Creole genotype is the most popular local breed of pig in Caribbean regions. The Guadeloupe Creole pig is originated from Iberian pig brought in the late 15^{th} and 16^{th} centuries which was first crossed with French native pigs such as the Normand and Craonnais and further crossed with various breeds such as the Large Black, Yorshire, Duroc and Hampshire (Canope and Raynaud, 1980; Rinaldo et al., 2003). This genotype is characterized by early sexual maturity, low prolificacy, high adiposity, good meat quality and its apparently good adaptation to harsh tropical environmental conditions. For this reason, this breed was introduced into our experimental facilities to study genetic variability of heat tolerance. The data covered the period between June 2002 and April 2005 and two successive seasons were determined a posteriori from average monthly daily ambient temperature (°C) and relative humidity (%): a warm season (24.1±1.0°C and 90.4±4.4%, on average) and a hot season (26.0±0.7°C and 87.6±5.5% on average).

Over the gestation period, sows were restrictively fed a conventional diet based on maize, wheat middlings and soybean meal (13 MJ DE/kg, 140 g CP/kg). The lactation diet was formulated to meet or exceed requirements for all nutrients (NRC, 1998). Farrowing room conditions and the feeding plan during the gestation and lactation periods have been previously described by Gourdine et al. (2006a). To sum up, feed was distributed once per day between 0700 and 0800 and sows had free access to water provided by a low-pressure nipple drinker. Lactation length was approximately 4 weeks (27.4±2.4 d on average). Infrared lights provided supplemental heat for the piglets during the entire lactation period. During the 48-h post farrowing period, litter size was standardized by cross-fostering within breed at 8 or 9 piglets per litter, and at 10 or 11 piglets per litter, in Creole (CR) and Large White (LW) sows, respectively. From d 21 of lactation, piglets were offered *ad libitum* creep feed containing 15.3 MJ DE per kg, 20% CP and 1.47% crude lysine. From weaning to d 14 after weaning, sows were observed twice daily for the onset of standing estrus in presence of a mature boar. Other signs of estrus such as vulva swelling or reddening or reaction to back-pressure were also checked. Sows that were detected in standing estrus were mated twice within a maximum 24-h interval, using either supervised natural mating or artificial insemination with boar or semen from the same genotypes. Pregnancy diagnosis was performed using boar passage and confirmed by ultrasonography three weeks after insemination.

Measurements

Backfat thickness and BW were measured on the day after farrowing and at weaning. Backfat thickness measurements were ultrasonically (Agroscan, E.C.M., Angoulême, France) carried out at 65 mm from the midline of the back beside the shoulder and the last rib on each flank. The total number of piglets born, born alive, stillborn and dead during lactation were recorded for each litter. Piglets were individually weighed at birth, at d 7, 14 and 21 of lactation and at weaning. For all sows, average daily feed intake (ADFI) was determined as the difference between the amount of feed offered and the amount of refusals collected on the next morning between 0600 and 0800. Rectal temperature (RT) was measured twice daily (i.e. at 0700 and 1200 which corresponded to minimum and maximum values of daily ambient temperature (Gourdine et al., 2006b) with a digital thermometer (Microlife Corporation, Paris, France), every Monday and Thursday from the Monday before farrowing to the Monday after weaning. Hence, RT were measured at -3, 0, 4, 7, 11, 14, 18, 21, 25, 28, and 32 days of lactation (with d 0 = farrowing day).

Statistical analyses

Two seasons were determined according to the average monthly ambient temperature and relative humidity obtained from climatic measurements between June 2002 and April 2005: a warm season between November and April and a hot season between May and October. When lactation occurred over two successive seasons, the lactation of a sow was attributed to the season in which the sow spent the largest number of days in lactation. The statistical model included the fixed effects of breed (CR vs. LW), season of lactation (warm vs. hot), parity (primiparous vs. multiparous) and their interactions, the effect of contemporary group within season and a random sow effect. Because of creep feed consumption from d 21 of lactation, milk production was estimated only over the first 3 weeks from calculation of mean daily milk dry matter with piglet average daily gain (g/d) (Noblet and Etienne, 1989; DM_L =

Table 1. Effect of breed, season and parity number on performance of lactating sows and their litters (Least square means)*

Item	Breed				Parity		SEM	Statistical analysis[b]
	Large White		Creole		Primiparous	Multiparous		
	Warm[a]	Hot[a]	Warm[a]	Hot[a]				
No. lactations	52	57	59	54	56	166		
No. sows	34	37	39	33	56	69		
Parity number	3.1	3.1	3.0	3.0	1.0	3.8		
ADFI, kg	4.66^x	3.74^y	3.48^y	3.01^z	3.68^y	3.77^y	0.63	B**, S**, B×S*, G**
ADFI (g/d $kg^{-0.75}$ d)	82.8^x	68.6^y	75.2^z	69.3^y	80.0^x	68.0^y	13	P**, S**, B×S#, G**
Body weight (kg)								
At farrowing	238.9^x	227.4^x	181.1^y	162.9^y	187.8^y	217.3^x	8.8	B**, P**, S**, P×B**, G**
Loss during lactation	4.9	10.9	8.2	9.4	8.4	8.3	14.8	G**
Backfat thickness (mm)								
At farrowing	19.2^x	22.8^x	37.6^y	36.9^y	26.7^x	31.5^y	6.0	B**, P**, B×S#, G**
Loss during lactation	1.8^x	4.6^y	6.0^z	4.7^y	3.2^y	3.8^y	4.9	B*
Litter size at weaning	8.2^x	9.0^y	7.9^x	7.7^x	8.2^x	8.2^x	1.8	B*, G*
Piglet ADG (g/d)	219^x	196^y	197^y	188^z	193^y	208^x	29	B*, P*, S*
BW at weaning (kg/piglet)	7.3^x	6.8^y	6.5^y	6.3^y	6.4^y	7.0^x	1.0	B**, P*, S#, B×P*, G*
Milk production[d] (g/d piglet)	776^x	698^y	703^x	670^y	678^y	747^x	142	S*, P**

* From an analysis of variance with a linear mixed model including the effects of breed (B), season (S), parity (P), and their interactions, and effect of group of sows within season (G) as fixed effects. The effect of sow was tested as a random effect. Statistical significance: ** $p<0.01$, * $p<0.05$, # $p\leq0.10$; Season: Warm season: November to April. Hot season: May to October; Metabolic body weight $BW^{0.75}$ = (BW at weaning$^{1.75}$ BW at farrowing$^{1.75}$)/(1.75× (BW at weaning-BW at farrowing)) adapted from Labroue et al. (1999); Daily milk production over the first 21 days of lactation was estimated from piglet growth rate between d1 and d21 using the equation of Noblet and Etienne (1989) for milk dry matter and assuming that milk has a 18% dry matter content; $^{x, y, z}$ In a row, for each main effect, least square means without a common superscript letter differ ($p<0.05$).

0.72×ADG-7, where DM_L, dry matter of milk (g/piglet d); ADG piglet average daily gain (g)) and assuming that milk had a 18% dry matter content (Gourdine et al., 2006c). The performance of sows and their litter during lactation were analyzed using the MIXED procedure of SAS/STAT (Version 8.1, SAS Inst., Inc., Cary, NC, 1999) with breed, season, parity, contemporary group of sows within season and their interactions as fixed effects. The random effect of the sows was also studied. The average daily RT (RT_{av}) (defined as the mean of RT measurements at 0700 and at 1200). RT measured at 0700 (RT_{07}) and at 1200 (RT_{12}), and the daily variation between RT_{07} and RT_{12} (ΔRT_{12-07}) were pooled per sow over the lactation period. These data were analyzed using the same previous model. Preliminary results from the Shapiro-Wilk tests for normality of RT provided insufficient evidence to reject the assumption of normality ($p>0.15$). Consequently, RT was studied as a raw variable but a test for normality was performed on residual values to confirm normality distribution.

Residual values of lactating and reproductive performance were computed from the preceding models (without the random effect of sow) and correlation coefficients in the CORR procedure of SAS/STAT were used to identify possible residual correlations between RT and sows performance within each breed and parity level. A Fisher Z transformation was used to compare the correlation coefficients between primiparous and multiparous sows within breed (COMPCORR Macro of SAS/STAT); a Bonferroni correction was applied to take into account multiple comparisons of correlation coefficients. Data for RT_{av}, RT_{07}, RT_{12} and ΔRT_{12-07}, during the whole period of measurements (i.e., from d -3 to d 32), were analyzed using the MIXED procedure of SAS/STAT with the fixed effects of breed, parity, season, day of measurements and their interactions. Because of the unequal number of observations between days, least-squares were weighed with the inverse of the variance of RT at each day of measurements. The effect of day was included in the model and analyzed as repeated measures (day) with an 11×11 unstructured covariance matrix (UN). This parametric covariance structure is useful when the structure is unknown, when the assumptions of stationarity (i.e. constant variances over time and equal correlations between measurement equidistant in time) are not met and when measurements are made on unequally spaced time intervals (Nunez-Anton and Zimmerman, 2000).

To evaluate the importance of individual differences for RT parameters, attention was paid on the variability between and within sows and comparison was assessed in two ways. First, a comparison between the standard deviation of the random effect of the sow in the linear mixed models with the standard deviation of the residuals was performed. Secondly, four variables were constructed, defining intra-sow and inter-sow variability (within contemporary group), for RT_{av}, RT_{07}, RT_{12}, and ΔRT_{12-07}. The intra-sow variability was assessed by computing the standard deviation of RT mean for each lactation of one sow. Likewise, the inter-sow variability was calculated as the standard deviation of the mean of RT values for each of the 11 d of measurements across sow's lactations within the

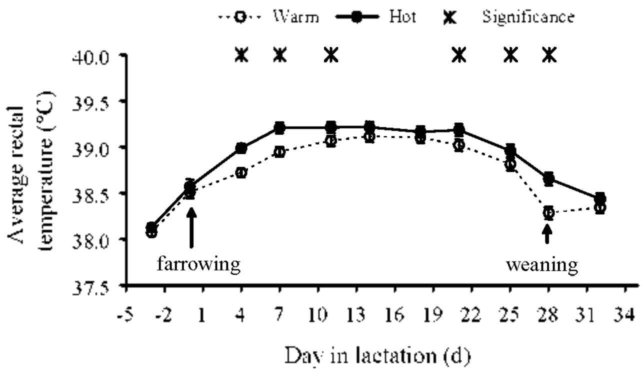

Figure 1. Effect of season on the kinetics of the average daily rectal temperature measured from d -3 to d 32 (least square means ±SEM); each point represents the least square mean of 111 lactations for both seasons; * rectal temperature was significantly affected by season (p<0.05).

same contemporary group. Analyses of variance were performed on these four variables with fixed effects of breed (CR vs. LW), type of variability (intra vs. inter) and their interactions, and effect of contemporary group.

The effects of season in a tropical humid climate, parity and breed on performance of sows during lactation have been investigated and discussed in a previous paper (Gourdine et al., 2006c). In the present study, results presented are least square means. Results on sow performance during lactation will be shortly presented with most attention devoted to changes in RT.

RESULTS

Sows performance

During the hot season, ADFI was lower than during the warm season (3,380 vs. 4,080 g/d; p<0.01) (Table 1). Irrespective of season, ADFI was higher (p<0.01) for LW than CR sows (4,200 vs. 3,250 g/d). However, this difference was no longer significant (p = 0.29) when ADFI was considered with respect to metabolic BW (75.7 vs. 72.2 g/d $kg^{-0.75}$ BW in LW and CR sows, respectively). An interaction between breed and season was found for feed intake (p<0.10). During the hot season, the decrease in ADFI (in g/d or in g/d $kg^{-0.75}$ BW) was more pronounced in LW than in CR sows (-920 vs. -480 g/d and -14.0 vs. -6.0 g/d $kg^{-0.75}$ BW). ADFI was not different among parities (3,680 vs. 3,770 g/d; p = 0.40, in primiparous and multiparous sows, respectively) but when expressed with respect to $BW^{0.75}$, it was greater in primiparous than in multiparous sows (80.0 vs. 68.0 g/d $kg^{-0.75}$ BW, respectively; p<0.01). After farrowing, LW sows were heavier than CR sows (233 vs. 172 kg, respectively; p<0.01) and had thinner backfat thickness (21.0 vs. 37.0 mm; p<0.01). The lactation BW loss was found to be affected (p>0.17) neither by season nor by breed (8.4 kg on average). However, backfat thickness loss was higher in CR than in LW sows (4.5 vs. 2.5 mm; p<0.05). Litter size at weaning was lower in CR than in LW sows (7.8 vs. 8.6 piglets; p<0.05) but was affected neither by season (p = 0.44) nor by parity (p = 0.99). Between d 1 and weaning, piglet daily BW gain was higher during the warm than the hot season (210 vs. 190 g/d; p<0.05). It was also higher in LW than in CR sows (210 vs. 190 g/d; p<0.05). Estimated milk production per piglet was higher during the warm than during the hot season (740 vs. 680 g/d; p<0.05) and it was also affected by parity (p<0.01) with greater values in multiparous than in primiparous sows (750 vs. 680 g/d).

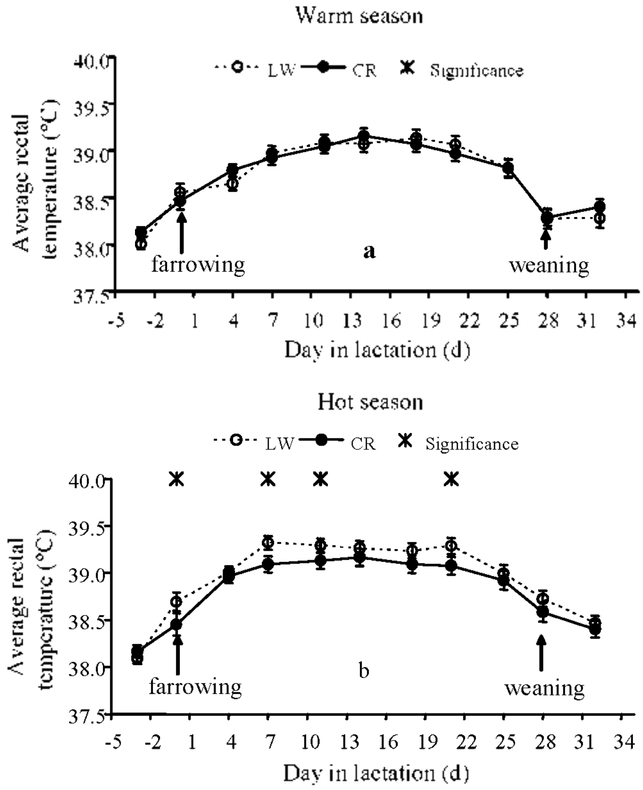

Figure 2. Effect of breed and season on the kinetics of the average daily rectal temperature measured from d -3 to d 32 (least square means±SEM); each point represents the least square mean of 59 and 52 lactations of Large White and Creole sows, respectively during the warm season; 54 and 57 lactations of Large White and Creole sows, respectively during the hot season; * rectal temperature was significantly affected by breed (p<0.05).

Rectal temperature of the sows

Whatever the hour of measurement, RT increased from d -3 to d 7 (+0.9°C) and decreased from d 25 to d 32 (- 0.6°C) (Figure 1). RT_{av} was higher (p<0.05) during the hot season than during the warm season from d 4 to d 11 and from d 21 to d 28 (Figure 1). During the warm season, no significant differences in RT_{av} between breed with advancement of lactation were found (Figure 2). In contrast, RT_{av} was greater in LW sows at farrowing, from d 7 to d 11

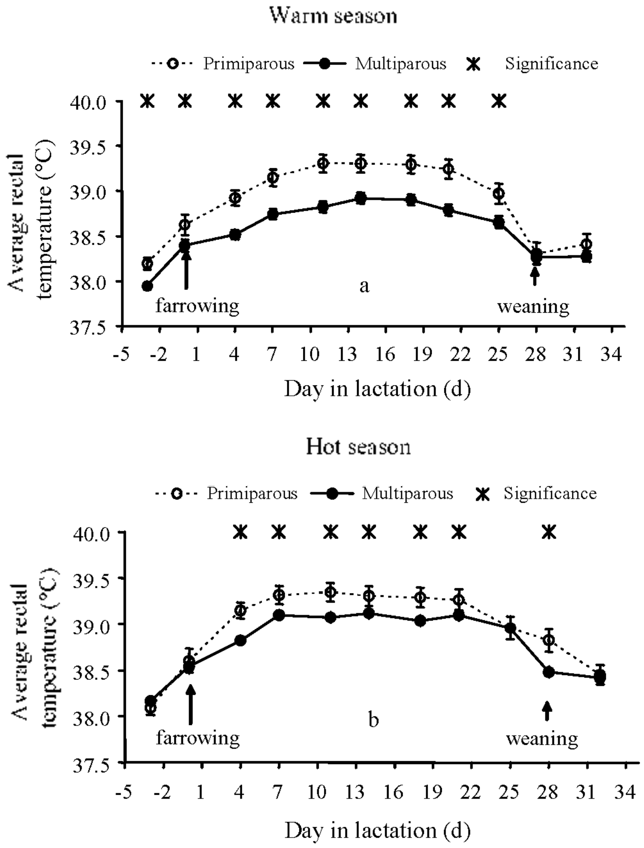

Figure 3. Effect of parity and season on the kinetics of the average daily rectal temperature measured from d -3 to d 32 (least square means±SEM); each point represents the least square mean of 29 and 82 lactations of primiparous and multiparous sows, respectively during the warm season; 27 and 84 lactations of primiparous and multiparous sows, respectively during the hot season; * rectal temperature was significantly affected by parity (p<0.05).

and on d 21 during the hot season. Whatever the season, RT_{av} was higher (p>0.4) in primiparous than in multiparous sows from d 4 to d 21, but the daily change was not affected by parity (Figure 3).

The effects of breed, season and parity on the average daily RT during lactation (i.e., the average value from d 0 to d 28) are presented in Table 2. Whatever the time of measurement (0700 or 1200 h), RT was higher during the hot than during the warm season (38.9 vs. 38.6°C; p<0.01). However, RT measured at 1200 (RT_{12}) was higher that RT_{07} (39.2 vs. 38.3°C, on average) and its diurnal variation between 0700 and 1200 ($\Delta RT_{12\text{-}07}$) was higher in hot than in warm season (0.9 vs. 0.8°C; p<0.01). Breed did not affect RT_{av}, RT_{07}, and RT_{12} but it had a significant effect on $\Delta RT_{12\text{-}07}$ with a higher value in LW than in CR sows (0.9 vs. 0.8; p<0.05). Irrespective of the breed or the season, RT_{07} and RT_{12} were greater in primiparous than in multiparous sows (38.5 vs. 38.3°C and 39.2 vs. 39.1°C, at 0700 and 1200 h, respectively; p<0.05) but $\Delta RT_{12\text{-}07}$ was greater in multiparous than in first parity sows (0.9 vs. 0.8°C; p<0.05). The breed×season interaction effect was found to be significant for both RT_{07} and RT_{12} measurements: during the hot season, the increase in RT being more pronounced in LW than in CR sows (+0.3 vs. +0.1°C for RT_{07}, p = 0.07; +0.5 vs. +0.3°C for RT_{12}; p<0.05). A breed×parity interaction was found for RT_{07} and RT_{12}, (Figure 4): the difference between primiparous and multiparous sows was more pronounced in CR than in LW sows (+0.3 vs. +0.1°C for RT_{07} and +0.1 vs. +0.0 for RT_{12}, respectively; p<0.05).

According to analyses of variance obtained with linear mixed models on RT_{07}, RT_{12}, the variance accounted for by individual sows represented 79 to 90% of the total variance. Intra and inter-variability in RT at 0700 did not differ but variability for RT at 1200 was greater in LW than in CR sows (p<0.05) and intra-variability was greater than inter-variability (p<0.05).

DISCUSSION

Rectal temperature (RT) is one of the criteria most frequently used in the literature to characterize the animals

Table 2. Effect of season, breed and parity on the average daily rectal temperature during lactation (least squ are means)*

Item	Breed				Parity		SEM	Statistical analysis[b]
	Large White		Creole		Primiparous	Multiparous		
	Warm[a]	Hot[a]	Warm[a]	Hot[a]				
No. lactations	52	57	59	54	56	166		
No. sows	34	37	39	33	56	69		
Parity number	3.1	3.1	3.0	3.0	1.0	3.8		
RT_{av} (°C)[c]	38.6^{x}	39.0^{y}	38.7^{z}	38.9^{w}	38.8^{w}	38.7^{z}	0.2	S**, P**, B·S*, B·P*, G**
RT_{07} (°C)[c]	38.2^{x}	38.5^{y}	38.3^{x}	38.5^{y}	38.5^{y}	38.3^{x}	0.2	S**, P**, B·S†, B·P**, G**
RT_{12} (°C)[c]	39.0^{x}	39.4^{y}	39.0^{x}	39.3^{z}	39.2^{z}	39.1^{x}	0.2	S**, P*, B·S*, B·P*, G**
$\Delta RT_{12\text{-}07}$ (°C)[c]	0.8^{x}	1.0^{y}	0.7^{z}	0.8^{x}	0.8^{x}	0.9^{y}	0.2	B*, S**, P*, G**

* From an analysis of variance with a linear mixed model including the effects of breed (B), season (S), parity (P) and their interactions, and effect of group of sows within season (G) as fixed effects. The effect of sow was tested as a random effect. Statistical significance: ** p<0.01, * p<0.05, † p≤0.10; Season: Warm season: November to April. Hot season: May to October; RT_{av}: average daily rectal temperature; RT_{07}: average daily rectal temperature measured at 0700; RT_{12}: average daily rectal temperature measured at 1200; $\Delta RT_{12\text{-}07}$: gradient RT_{12} and RT_{07}; [w, x, y, z] In a row, for each main effect, least square means without a common superscript letter differ (p<0.05).

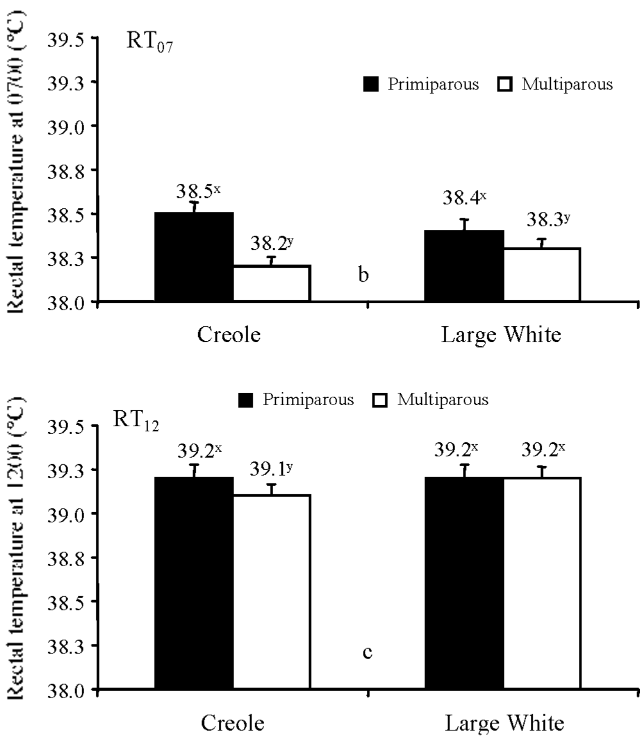

Figure 4. Effect of breed and parity on the average daily rectal temperature during lactation; $^{x, y}$ least square means without a common superscript letter differ ($p<0.05$);each point is the least square mean of 56 lactations of primiparous sows (29 Large White and 27 Creole) and 166 lactations of multiparous sows (80 Large White and 86 Creole), respectively.

thermoregulatory responses to heat stress (Holmes, 1973; Kadzere et al., 2002). Interpretations have often been based on the assumption that RT is the result of the entire thermoregulation process which mainly explains that RT was used to characterize the body ability to maintain the thermal balance in beef cattle (Amakiri and Funsho, 1979; Morris et al., 1989) or in pig (Huynh, 2005; Renaudeau, 2005). In addition, RT measurement is inexpensive and easily realizable. Finally, in genetic selection view, RT is one of the heat tolerance parameters for which estimations of heritability and correlations with other traits are available (Mackinnon et al., 1991; Burrow, 2001).

Effect of hour of measurement and stage of lactation on rectal temperature

Independently of season, rectal temperature (RT) was higher at 1200 h (RT_{12}) than at 0700 h (RT_{07}). In fact, RT_{07} and RT_{12} coincide with the minimum values (i.e. 21.7 and 24.2°C around 0700 in the warm and the hot seasons, respectively) and the maximum values (i.e. 28.2 and 31.9°C in the warm and the hot seasons, respectively) of ambient temperature. According to previous results reported in buffaloes (Sethi et al., 1992; Koga et al., 1999) or in pigs (Korthals et al., 1999), diurnal variation of body temperature follows that of ambient temperature, suggesting that in addition to feeding behaviour and physical activity, circadian rhythm of body temperature is affected by changes in external ambient temperature.

Whatever the hour of measurement, RT increased at farrowing (i.e. from d -3 to d 4), remained relatively constant thereafter during lactation and decreased after weaning (i.e., from d 28 to d 32). Similar variations in RT were obtained by Prunier et al. (1997) in primiparous sows and by Littledike et al. (1979) and Renaudeau et al. (2001) in multiparous sows. From these results, it can be hypothesized that the increase in RT during lactation is a direct consequence of the increase in metabolic heat production (HP) related to milk synthesis. Likewise, the decrease in RT after weaning reflects a decline in HP related to the interruption of milk synthesis with weaning.

From d 4 to d 25, RT remained constant which agrees with findings of Quiniou and Noblet (1999) and Renaudeau et al. (2001) in sows kept at 29°C during the whole lactation period. These authors suggested a quick acclimation to high temperature (within 3 days) not followed by a further adaptation thereafter. In contrast, Schoenherr et al. (1989) and more recently Spencer et al. (2003) noted a significant decrease in RT during lactation, and suggested a possible long term acclimation to elevated temperature (i.e. 32°C) as lactation progressed. The discrepancy between both sets of results could be related to the difference in ambient temperature (29 vs. 32°C) and it can be hypothesized an existence of a threshold of ambient temperature from upwards long-term acclimation responses to elevated ambient temperature.

In a recent study, Thiel et al. (2004) showed that HP in sows did not vary significantly between wk 2 and wk 4 of lactation whereas feed intake and milk production increased. They suggested that constant HP throughout the lactation period could be related to a better efficiency of ME utilisation for milk production. In the present work, ADFI was also relatively constant but milk production increased with the advancement of lactation (results not shown). Because the efficiency of utilization of dietary ME is lower than that of energy from body reserves (72 vs. 88%, Noblet et al., 1990) and assuming that heat loss capacity did not vary over the lactation period, it can be hypothesized that a constant HP and, consequently a constant RT, with advancement of lactation would be related to an overall increase in energy efficiency for milk production. This is probably due to either an increase in body reserves mobilization or to an increase in efficiency of dietary ME utilization for milk production or some combinations of them.

Effect of season on rectal temperature

Under tropical humid climate conditions, average daily ambient temperature frequently exceeds the evaporative critical temperature (i.e. estimated at about 22°C by Quiniou and Noblet. 1999). Consequently, sows were heat stressed most of the time during lactation under our conditions. Moreover, infrared lights providing supplemental heat for the piglets may have emphasized the effect of elevated ambient temperatures.

A high RT value recorded in hot season (i.e. 38.9°C) implies that thermogenesis exceeds thermolysis or that heat loss mechanisms are saturated. When we compare warm and hot seasons in LW sows. RT_{av} increased by about 0.15°C for each degree rise in ambient temperature (i.e. between 24.1 and 26.0°C). According to the results of Renaudeau (2005) and Huynh (2005) obtained in growing pigs. high relative humidity (RH) increases the threshold temperature at which RT begins to increase (i.e. upper critical temperature) and the RT response to rise in ambient temperature. Thereafter, it can be suggested that high RH encountered in a tropical humid climate accentuates the negative effect of elevated temperature on sow RT.

The ADFI in LW sows was reduced by about 900 g/d in hot season but the associated reduction of metabolic HP was insufficient to prevent an increase in RT during hot season. In fact, according to the low residual correlation coefficients, the relationship between ADFI and RT remains unclear in LW sows, implying that the reduced ADFI has no direct effect on RT. This finding is in contradiction with the literature in lactating sows (Lorschy et al., 1991; Quiniou and Noblet. 1999) and in lactating cows (Nardone, 1998; Spiers et al., 2004). In these latter studies, climatic conditions were experimentally controlled and the range of temperature was higher than that of our uncontrolled conditions. Finally, this suggests that in our experimental conditions, other uncontrolled factors would be interacting in the relationship between RT and ADFI.

In the present study, it seems that different strategies were adopted by lactating sows to cope with hot conditions. According to a multiple correspondence analysis and a cluster analysis (not presented), some sows (21%) decreased their feed consumption to reduce their heat production and to avoid an accentuated increase in their RT whereas others maintained their feed intake with an increase in their RT. In the literature, differences between individuals have been found in physiological responses (Hagen et al., 2005; Refinetti and Piccione. 2005). In the present study, individual variability accounted for more than 79% of the variance. That suggests that genetic variations as well as phenotypic differences in RT affects variability of lactating sow. In cattle and in poultry, moderate heritability of RT was estimated (h^2 = 0.29 on average) (Turner, 1982 and 1984; Morris et al., 1989; Taouis et al., 2002) with moderate to high phenotypic and genetic correlations between RT and variables of production performance. Furthermore, in the present study, the analysis of intra and inter-variability in daily RT change showed that intra-variability was greater than inter-variability. This finding suggests that an 'average' lactating sow is a sensible notion, but daily adjustments in daily RT differs between sows. As reported by Renaudeau et al. (2004), genetic and phenotypic estimations based on daily fluctuation in RT may be different than estimations based on average RT parameters.

Effect of parity on rectal temperature

In the present study, RT was greater in first parity than in multiparous lactating sows. To our knowledge, the effect of parity on rectal temperature is poorly documented in lactating sows. In lactating buffaloes, Sethi et al. (1992) found no statistical difference between parities, but according to a lower respiration rate in primiparous, the authors suggested a greater heat tolerance capacity in younger animals. In lactating cows, Saama and Mao (1993) did not found an effect of parity on cow's heat production. Surprisingly, in a simulation based on the same milk production and the same body reserves mobilization. Makkink and Schrama (1998) found an increase in the upper critical temperature with increasing sow BW. In contrast, a probable increase in thermogenesis associated with a higher fasting heat production and HP related to the rise of milk production would have to make the multiparous more sensible to heat stress.

From our results, it has been hypothesized that a decrease in ME efficiency for milk production and (or) a decrease in heat loss efficiency could explain the lower ability to maintain homeothermia in primiparous sows. Assuming that maintenance requirement of metabolizable energy is 456 kJ $kg^{-0.75}$ (Noblet and Etienne. 1987), the amount of dietary ME above maintenance available for milk production was higher in primiparous than in multiparous sows (80.0 vs. 68.0 g/d $kg^{-0.75}$ BW) whereas milk yield was found to be slightly lower in first parity sows. In fact, ME intake in primiparous sows was used to meet both growth and milk production requirements which could explain the lower apparent efficiency of dietary ME for milk synthesis.

Furthermore, it can not be excluded that lower RT observed in multiparous sows is an indirect consequence of culling policy of our experimental herd: after the first weaning, sows are culled mainly for reasons involving reproductive failure (non return in oestrus, fertility problems) and lactation failure (low milk production or prolificacy, locomotion problems). Consequently, it can be suggested that the discarded sows after first lactation were those with a reduced ability to acclimate to hot conditions. In addition, when RT evolution of lactating sows was analysed in 3 consecutive parities (from parity 1 to parity 3 and corrected for BW, VFI and milk production differences, results not presented), a linear decrease in RT with parity was observed (-0.096°C, $p<0.05$), suggesting a long term adaptation to heat stress with age.

Effect of breed on rectal temperature

The effect of breed on thermoregulation capacity is poorly documented in pigs. Herpin et al. (2004) reported similar cold thermoregulatory abilities between Meishan and European piglets at birth, but different BW effect within breed on thermoregulatory capacity. In beef cattle, Finch (1985) measured a more efficient thermolysis in Brahman than in Shorthorn cattle. Koga et al. (1999) indicated that RT was lower in buffaloes than in cows but the amplitude of diurnal change of RT was greater in buffaloes. The authors attributed this fact to a lower basal heat production in buffaloes, but also to a greater heat transport through changes in blood flow.

In the present study, the average RT calculated for the whole lactation period (i.e. from d 0 to d 28) was comparable for both breeds but diurnal variation in RT was slightly greater in LW than in CR sows which contrasts with results of Koga et al. (1999). Furthermore, with regard to residual correlations between RT and performance during lactation, it seems that factors susceptible to affect RT variation differ between breeds. Indeed, our study indicates that RT of LW sows was more associated with body condition at farrowing and milk production for primiparous sows and body change during lactation for multiparous sows, whereas RT variation in CR sows was more related to change in feed intake level. However, with this set of data, correlation coefficients were not accurate enough for predictive purposes.

In contrast to other species like ruminant or poultry (as reviewed by Nardone, 1998; West, 2003), limited information is available in pigs about the combined effect of heat stress and breed on RT. Breed differences have been reported for responses to heat stress between halothane positive and negative pigs with higher RT and heat production in pigs possessing the halothane gene (Aberle et al., 1975; Tauson et al., 1998).

Based on ADFI data, our study shows that the negative effect of hot season was more attenuated in CR than in LW sows. Similarly, the average RT was lower in CR and LW sows during the hot season. The between breed difference may be the result of a lower thermogenesis or of a better capacity for dissipating heat in CR than in LW sows. A previous study (Gourdine et al., 2006b) indicated that whatever the season, physical activity during lactation, i.e., the duration of the standing or sitting position, did not differ between LW and CR sows. Consequently, it can be excluded that between breed difference in RT change with season is due to differences in physical activity during lactation, but rather in fasting and metabolic HP differences as a result of differences in body condition and in production level. Indeed, fasting HP is a function of BW and body composition (van Milgen et al., 1998; Noblet et al., 1999). Consequently, according to their lower BW and their greater body fat content, it can be assumed that fasting HP of CR sows is lower than LW sows. Similarly, lower feed intake in CR sows, related to lower milk production, may result in lower metabolic HP. Furthermore, the better heat tolerance in CR than in LW sows may be attributable to their greater thermolysis capacity. In an experiment involving a low number of crossbred CR×LW and purebred LW piglets (n = 4), Berbigier (1975) showed a better non-evaporative heat loss capacity in crossbred piglets. This hypothesis agrees with the results reported by Finch (1985) in a beef cattle comparison. The author suggested a great contribution of ability to dissipate non-evaporative heat in the regulation of body temperature. In growing pigs, Renaudeau (2005) found that the upper critical temperature is slightly greater and the increase in RT above 30°C is reduced in CR pigs than in LW pigs. However, further studies in pigs are needed to understand the effect of breed to season interaction on thermoregulation responses.

IMPLICATIONS

The present study confirms the negative effect of hot season on sow's performance and RT. Even if the sow decreases its metabolic heat production level, RT increases during the hot season. Furthermore, our results show an improved heat tolerance with parity, suggesting that mechanisms involved in heat stressed sows are different between primiparous and multiparous sows. Finally, this study also indicates that CR sows would have a better tolerance to heat stress than LW sows, probably related to a lower heat production due to a lower BW and a lower production level and probably combined with a better heat loss capacity. However, further studies are required to examine the genetic variation among sows, both between and within breed.

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