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Effects of dietary protein concentration and amino acid supplementation on the feeding behavior of multiparous lactating sows in a tropical humid climate[1]

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ABSTRACT: Forty-seven mixed-parity Large White sows were used to determine the effect of diets with reduced CP content or supplemented with essential AA on 28-d lactation feeding behavior under humid tropical climatic conditions. The study was conducted at the INRA experimental facilities in Guadeloupe, French West Indies (latitude 16° N, longitude 61° W) between February 2007 and January 2008. Two seasons were distinguished a posteriori from climatic measurements continuously recorded in the open-front farrowing room. The average ambient temperature and average daily relative humidity for the warm season were 23.6°C and 93.8%, respectively. The corresponding values for the hot season were 26.1°C and 93.7%. The dietary experimental treatments were a normal protein diet (17.3%), a low protein diet (14.1%), and a normal protein diet supplemented with essential AA (17.6%). No interaction between season and diet composition was found for all criteria. Average daily feed intake was less ($P <$ 0.01) during the hot season (4,559 ± 161 vs. 5,713 ± 204 kg/d). Meal size was reduced during the hot season (542 ± 37 vs. 757 ± 47 g/meal; $P < 0.01$). Daily ingestion time (45.5 ± 3.2 vs. 55.8 ± 4.0 min/d; $P <$ 0.05) was less in the hot season. Meal size was reduced during the hot season at night ($P < 0.01$). In both seasons, daily feed intake, feed ingestion, and rate of feed intake were less ($P < 0.01$) during the nocturnal period than during the diurnal period. The number of meals per day was not affected ($P > 0.10$) by season or diet composition. Daily feed intake was greater for the sows fed the low protein diet when compared with normal protein treatments ($P < 0.05$). Duration of standing was not affected by diet or season ($P > 0.05$), and averaged 126 ± 35 min/d. This study confirms that feeding behavior variables of the lactating sow are affected by seasonal pavariations of the tropical climate. Irrespective of season, the reduction of CP content improved feed consumption under tropical conditions.

Key words: dietary protein, feeding behavior, lactation, sow, tropical climate

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INTRODUCTION

Ambient temperature is the major environmental factor that affects the performance of lactating sows in tropical climates. When the ambient temperature increases above the thermoneutral zone (18 to 20°C), voluntary feed intake is reduced to reduce heat production caused by the thermic effect of feed. The reduction in feed intake has associated negative effects on milk production and reproductive performance (Renaudeau et al., 2005). To understand the control and regulation of feed intake in hot environments, and to establish an appropriate feeding strategy, it is important to study factors affecting feeding behavior. Various authors have shown that ambient temperature has an important and

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critical role in the regulation of voluntary feed intake (**VFI**). In controlled climatic rooms with low relative humidity (**RH**) and constant daily temperatures, Quiniou et al. (2000b) reported a curvilinear reduction of feed intake when the temperature increased above 22°C, with an accentuated reduction of meal size and meal number above 27°C. Quiniou et al. (2000a) also demonstrated that daily fluctuating temperatures had smaller effects on VFI than constant daily temperatures in connection with an adaptation of feeding behavior.

Diets with reduced CP content resulted in less heat production (Le Bellego et al., 2001). Such diets may be better tolerated in tropical climate conditions. Results obtained in growing pigs or in lactating sows support this hypothesis (Johnston et al., 1999; Renaudeau et al., 2001, 2002; Spencer et al., 2005).

Previous studies have focused on the effect of elevated temperature on ADFI and lactation performance. Studies on the changes in feeding behavior associated with the reduction of VFI under hot conditions are limited. The aim of the present study was to evaluate the effects of diets with a reduced thermic effect of feed or supplemented with an AA complement on the performance and feeding behavior of multiparous lactating sows in tropical climatic conditions.

MATERIALS AND METHODS

Care and use of animals were performed according to the certificate of authorization to experiment on living animals (issued by the French ministry of Agriculture to C. Anais, head of the experimental unit).

Experimental Design

A total of 47 multiparous Large White sows in 10 successive replicates of 8 to 10 animals were used in a study conducted at the INRA experimental facilities in Guadeloupe, French West Indies (latitude 16° N, longitude 61° W), characterized as having a tropical humid climate (Berbigier, 1988). Within each group, the feeding behavior was measured on only 4 to 6 sows using electronic troughs; thus, a total of 47 sows were studied. This study covered the period between February 2007 and January 2008.

Within each replicate, sows were distributed in a completely randomized experimental design and assigned to 1 of 3 dietary treatments according to backfat thickness, parity order, and BW after farrowing. The dietary experimental treatments were a normal protein diet (**NP**; 17.3%), a low protein diet (**LP**; 14.1%), and a NP diet supplemented with an AA complement (**NP+**; 17.6%). The experimental diets (Table 1) were formulated using corn, wheat middlings, and soybean meal, and met or exceeded AA requirements of lactating sows (NRC, 1998). The NP and LP diets supplied the same concentrations of standardized digestible lysine (0.80 g/MJ of NE) and the NP+ diet supplied 0.95 g/MJ of NE. To calculate the composition of the AA complement, the lysine concentration was increased until the first essential AA became limiting (phenylalanine + tyrosine), after synthetic AA were added to maintain a constant ratio between the essential AA and lysine. Each morning, 53 g of the calculated AA complement was incorporated manually by mixing with the NP diet before it was offered to the sows. Chemical composition and nutritional value of diets are presented in Table 2. Diets were offered as pellets. Feed was prepared for 1 or 2 successive replicates and stored in a temperature-controlled room (24°C, 50 to 60% RH).

Animal Management

Sow management and feeding strategies were reported by B. A. N. Silva, J. Noblet, J. L. Donzele, R. F. M. Oliveira, J. L. Gourdine (INRA, Guadeloupe, French West Indies), and D. Renaudeau (unpublished data). Variations in ambient temperature, RH, and photoperiod closely followed outdoor conditions. After birth, piglets were handled for tooth cutting, umbilical cord treatment, and identification (ear tagging). On d 3, they received an intramuscular injection of 200 mg of iron dextran. If necessary, cross-fostering was done within the first 48 h after birth to standardize the litter size to 10 or 11 piglets. Piglets were weighed at birth and at 14, 21, and 28 d of lactation. On d 14, male piglets were castrated. After 21 d of lactation, piglets were offered creep feed, containing 15.3 MJ of DE/kg, 20% CP, and 1.47% crude lysine. Infrared lights provided supplemental heat for the piglets during the first 21 d of the lactation period. At weaning, sows were moved to a breeding facility and were presented to a mature boar twice daily to detect onset of standing estrus. From 28 d after mating, all sows were checked for pregnancy using ultrasonography (Agroscan, E.C.M., Angoulême, France).

Measurements

Sow and litter measurements were described by B. A. N. Silva, J. Noblet, J. L. Donzele, R. F. M. Oliveira, J. L. Gourdine (INRA, Guadeloupe, French West Indies), and D. Renaudeau (unpublished data). Individual feeding behavior was recorded during the ad libitum period (between d 6 and 27), using an electronic trough connected to a load cell and a computer. When the trough was detected by the load cell as being unsteady, it was recorded as a visit. After each visit, the time and amount of feed at the beginning and at the end of the visit were recorded. In addition to the electronic measurement of feed intake, morning refusals were manually collected and weighed at the same time, between 0700 and 0800 h, and the daily intake was determined as the difference between feed allowance and the refusals collected on the next morning. Standing or sitting duration was recorded over the ad libitum period by

Table 1. Ingredient composition of experimental diets[1] (as-fed basis) fed to lactating sows

Ingredient, g/kg	NP	LP	AA complement[2]
Corn	59.9	67.4	—
Soybean meal	24.4	10.6	—
Wheat middlings	8.6	14.3	—
Soybean oil	3.4	2.4	—
L-Lysine hydrochloride	0.020	0.415	29.6
DL-Methionine	—	0.109	17.3
L-Threonine	—	0.175	19.8
L-Tryptophan	—	0.064	4.3
Isoleucine	—	0.127	10.4
Valine	—	0.140	18.5
Monocalcium phosphate	1.0	1.0	—
Calcium carbonate	2.1	2.1	—
Salt	0.1	0.1	—
Minerals and vitamins[3]	1.1	1.1	—

[1]NP = normal protein diet; LP = low protein diet.

[2]AA complement calculation: lysine content was increased in the NP diet until the other essential AA (phenylalanine + tyrosine, histidine, arginine, leucine) became limiting following the NRC (1998) recommendations for AA:lysine: 111, 39, 55, 110, for phenylalanine + tyrosine, histidine, arginine, leucine, respectively. For calculation of the AA complement, an estimated ADFI of 5,000 g/d was used. A 53-g quantity of the AA complement was offered daily to each NP+ sow.

[3]The mineral and vitamin mixture supplied (g/kg of diet): 10 of Cu (as $CuSo_4$); 80 of Fe (as $FeSO_4 \cdot 7H_2O$); 40 of Mn (as MnO); 100 of Zn (as ZnO); 0.6 of I [as $Ca(IO_3)_2$]; 0.10 of CO (as $CoSO_4 \cdot 7H_2O$); 0.15 of Se (as Na_2SeO_3); 5,000 IU of vitamin A; 1,000 IU of vitamin D_3; 15 IU of vitamin E; 2 mg of vitamin K_3; 2 mg of thiamine; 4 mg of riboflavin; 20 mg of nicotinic acid; 10 mg of D-panthothenic acid; 3 mg of pyroxidine; 0.02 mg of vitamin B_{12}; 1.0 mg of folic acid; and 0.2 mg of biotin.

Table 2. Analyzed composition[1] of experimental diets[2] fed to lactating sows

Item	NP	LP	NP+
Analyzed composition			
Ash	5.5	5.3	5.6
CP	17.3	14.1	17.6
Starch	39.0	45.2	39.0
Ether extract	4.3	5.6	4.3
NDF	10.0	10.8	10.0
ADF	2.5	2.7	2.5
Digestible basis			
Lysine	0.80	0.80	0.97
Methionine + Cystine	0.49	0.48	0.68
Threonine	0.54	0.54	0.66
Tryptophan	0.18	0.17	0.21
Isoleucine	0.63	0.54	0.77
Leucine	1.36	1.07	1.36
Valine	0.71	0.65	0.86
Phenylalanine	0.82	0.56	0.82
Tyrosine	0.59	0.41	0.59
Tryptophan:LNAA,[3] %	4.52	5.37	4.83
Calculated nutritional value[4]			
NE, MJ/kg	10.2	10.1	10.2
Digestible lysine, g/MJ of NE	0.80	0.80	0.95
NE:ME, %	71.6	73.5	71.6

[1]All values adjusted to 88.0% of DM.

[2]NP = normal protein diet; LP = low protein diet; NP+ = normal protein diet plus an AA complement.

[3][Percentage of tryptophan/(% isoleucine + % leucine + % valine + % phenylalanine + % tyrosine)] × 100. LNAA = large neutral AA.

[4]NE values were estimated from the chemical composition of the diet and the equation of Noblet et al. (1994). Standardized digestible AA contents were calculated from the analyzed AA content and estimated standardized digestibility coefficients from Institut National de la Recherche Agronomique tables (Sauvant et al., 2004).

using an infrared barrier located in the middle of the crate, but the equipment did not allow standing and sitting to be distinguished.

Calculations and Statistical Analysis

Daily maximum, minimum, mean, and variance of the ambient temperature and RH were averaged for each replicate. These data were used to split the experimental period into 2 seasons through a principal components analysis (PRINCOMP procedure, SAS Inst. Inc., Cary, NC).

Feed consumption per visit was calculated as the difference between the amounts recorded just before and just after the visit. For each visit, feed consumption less than 20 g was considered an artifact caused by the movements of the sows on the slatted floor, and it was not taken into account for further calculations. Because of electronic problems with the load cells and some power failures, 2% of daily recordings were excluded from our study. Ingestion time of feed per visit corresponded to the difference between the time at the end and at the beginning of the visit. Sows exhibit short pauses during a meal, and these short intervals between visits must be differentiated from the longer ones between 2 different meals. For this purpose, a meal criterion (**MC** = 5 min; Gourdine et al., 2006), defined as the maximum length of within-meal intervals between 2 successive visits, was estimated. When 2 successive visits were separated by an interval shorter than MC, visits were merged into the same meal. Hence, from the calculated value of MC (i.e., 5 min), the following daily feeding behavior variables were calculated for each sow: number of meals per day, feed intake per day (g), total ingestion time per day (total duration of all the visits, min), total consumption time of feed (sum of the ingestion time and within-meal interval, min), rate of feed intake (total feed intake/total ingestion time, g/min), and feed intake per meal (g). For each replicate, sows were distributed among 6 crates that were equipped with the load cells; primiparous sows were not included in the feeding behavior study. Effects of season, diet composition, batch, parity, and their interactions on sow and litter performance were tested according to ANOVA (GLM procedure of SAS).

During the ad libitum period (between d 6 and 27), a total of 903 daily measurements of feeding behavior variables were made on 43 sows. These data were pooled per sow on a daily basis and were analyzed according to linear mixed model variance using the MIXED procedure of SAS/STAT, including the fixed effects of season, diet composition, day of lactation, and batch, and their interactions.

The mean feeding behavior components per sow over the ad libitum lactation period were also calculated according to photoperiod (day vs. night) and were analyzed according to a linear mixed model including the fixed effects of season, diet composition, batch, and their interactions. Finally, a mixed model was used to examine the fixed effects of season, diet composition, batch, and their interactions on the average hourly sow feed intake during lactation. Effects of season on feed ingestion were analyzed by generating contrasts between adjacent hourly values.

For all analyses using the MIXED procedure, the sow was considered as a random effect and the repeated measurement option of the mixed procedure of SAS was used with an autoregressive covariance structure to take into account the correlations between repeated measurements carried out on the same animal. Means comparison was performed using the Tukey test for contrasts. Probability values $\leq$0.10 and >0.05 were considered trends, whereas $P \leq 0.05$ was considered significant.

Table 3. Main characteristics of climatic variables recorded during the experiment[1]

Item	Season	
	Warm	Hot
Temperature, °C		
Minimal	20.5	22.7
Maximal	28.2	29.4
Mean	23.6	26.1
Relative humidity, %		
Minimal	83.0	87.1
Maximal	98.5	97.7
Mean	93.8	93.7
Duration of diurnal period,[2] h:min	11:40	12:20

[1]Seasons correspond to the means of daily values of ambient temperature and relative humidity. Warm season: February to April 2007 and November 2007 to January 2008. Hot season: May to October 2007.

[2]Diurnal period from 0620 to 1800 h and 0550 to 1811 h for the warm and hot season, respectively.

RESULTS

The main characteristics of both seasons are presented in Table 3. During the warm season, ambient temperature and RH averaged 23.6°C and 93.8%, respectively. The corresponding values for the hot season were 26.1°C and 93.7%, respectively. The duration of the diurnal periods were 11:40 and 12:20 (h:min) for the warm and the hot season, respectively.

The performance of multiparous sows measured for the feeding behavior is presented in Table 4. During the complete lactation period (between d 0 and 28), daily feed intake was less during the hot season (4,559 ± 171 vs. 5,713 ± 216 g/d; $P < 0.01$). The reduced milk production was associated with a reduced litter growth rate (7,349 ± 261 vs. 8,348 ± 329 g/d and 2,102 ± 66 vs. 2,397 ± 84 g/d, respectively, for the hot and warm season; $P = 0.02$). Daily feed intake was greater for the sows fed the LP diet when compared with those fed the NP and NP+ diets (5,654 vs. 4,876 g/d, respectively; $P < 0.05$).

According to the ANOVA, no interaction was observed ($P > 0.10$) between season and diet composition for lactation performance and feeding behavior components.

Table 4. Effect of season and diet composition on the performance of lactating sows and their litters over a 28-d lactation (least squares means)

	Diet[1]			Season[2]			
Variable	NP	LP	NP+	Warm	Hot	RSD[3]	Statistical analysis[4]
Lactation, n	16	16	15	18	29		
Average parity	3.4	3.5	3.7	3.8	3.3	1.5	
Lactation length, d	28.0	29.3	28.5	28.1	29.0	3.1	
ADFI, g/d	4,969	5,654	4,784	5,713	4,559	864	D,* S**
BW, kg							
After farrowing	249	247	254	251	250	29	
Loss during lactation	27	20	25	24	24	15	
Backfat thickness, mm							
After farrowing	14.1	14.9	14.8	14.0	15.4	2.9	
Loss during lactation	4.2	2.7	3.9	3.2	4.4	3.2	
Litter size at weaning	10.8	11.3	11.1	11.0	11.1	1.0	G*
Litter growth rate, g/d	2,281	2,264	2,203	2,397	2,102	354	S*
Weaning BW, kg/piglet	7.7	7.4	7.3	7.7	7.2	0.8	
Milk production,[5] g/d	7,939	7,886	7,720	8,348	7,349	1,396	S†

[1]NP = normal protein diet; LP = low protein diet; NP+ = normal protein diet plus an AA complement.
[2]Warm season: February to April 2007 and November 2007 to January 2008. Hot season: May to October 2007.
[3]RSD = residual SD.
[4]From an analysis including the effects of season (S), diet composition (D), the effect of parity (P), and the effect of batch of sows (G), and their interactions as fixed effects. The interaction between diet and season was not significant ($P > 0.10$).
[5]Daily milk production over the first 21 d of lactation was calculated from litter growth rate, litter size between d 1 and 21, and milk DM using the equation from Noblet and Etienne (1989).
†$P \leq 0.10$, *$P < 0.05$, **$P < 0.01$.

Daily feed intake during the ad libitum period (d 6 to 26) was affected by season ($P < 0.01$), whereby the feed intake was less during the hot season than in the warm season (4,559 ± 161 vs. 5,713 ± 216 g/d). Meal size was reduced during the hot season (542 ± 37 vs. 757 ± 47.1 g/meal; $P < 0.01$; Table 5). The daily ingestion time was less in the hot than in the warm season (45.5 ± 3.2 vs. 55.8 ± 4.0 min/d, respectively; $P < 0.05$).

Table 6 shows the effect of light pattern on the feeding behavior of lactating sows. No interaction between season and photoperiod or between diet and photoperiod was observed for all the feeding behavior criteria. The reduction of the nocturnal feed consumption was mainly explained by a reduction in meal size (693 vs. 620 g/meal), whereas meal frequency was not affected (4.3 meals/d, on average). The rate of feed intake was greater during the night. This result, combined with the reduced nocturnal feed intake, explained the lack of photoperiod effect on daily time of consumption (25.6 min/d, on average).

Table 5. Effect of season and diet composition on feeding behavior and duration of standing of lactating sows between d 6 and 26 postpartum (least squares means)

	Diet[1]			Season[2]			
Variable	NP	LP	NP+	Warm	Hot	RSD[3]	Statistical analysis[4]
Lactations, n	16	16	15	18	29		
No. of meals/d	8.7	8.1	9.5	8.1	9.4	2.7	
Feed intake, g/d	4,969[a]	5,654[b]	4,784[a]	5,713	4,559	864	D,* S,** G*
Feed intake, g/meal	655	733	557	757	542	215	D,† S,** G*
Ingestion time							
min/d	50.8	53.5	47.7	55.8	45.5	17.1	S*
min/meal	6.5	7.2	5.3	7.3	5.3	2.8	S*
Rate of feed intake, g/min	107	115	107	111	108	35	
Standing duration,[5] min/d	151	112	117	107	146	73	

[a,b]Within a row, adjusted means values with different superscripts are significantly different ($P < 0.05$).
[1]NP = normal protein diet; LP = low protein diet; NP+ = normal protein diet plus an AA complement.
[2]Warm season: February to April 2007 and November 2007 to January 2008. Hot season: May to October 2007.
[3]RSD = residual SD.
[4]From an analysis including the effects of season (S), diet composition (D), the effect of parity (P), and the effect of batch of sows (G), and their interactions as fixed effects.
[5]Standing duration values include time dedicated for feed consumption and correspond to the means of available values.
†$P \leq 0.10$, *$P < 0.05$, **$P < 0.01$.

Table 6. Effect of season and diet composition and light pattern on feeding behavior and duration of standing of lactating sows between d 6 and 26 postpartum (least squares means)

	Diet[1]			Season[2]			
Variable	NP	LP	NP+	Warm	Hot	RSD[3]	Statistical analysis[4]
Lactations, n	16	16	15	18	29		
No. of meals/d							
Day	4.9	4.3	4.5	4.3	4.9	1.6	
Night	4.3	3.7	4.4	3.9	4.4		
Feed intake, g/d							
Day	2,710[a]	3,158[b]	2,670[a]	3,266	2,426	679	D,* S,*** L,** G*
Night	2,260[a]	2,496[b]	2,115[b]	2,448	2,138		
Diurnal proportion of feed intake, %	55	56	55	57	53	10	D × S†
Feed intake, g/meal							
Day	680	761	640	813	575	237	S,** L,* G*
Night	628	719	514	707	533		
Ingestion time, min/d							
Day	26.0	28.9	25.0	30.0	24.0	10.5	S*
Night	25.0	25.3	23.2	26.4	22.6		
Rate of feed intake, g/min							
Day	124	121	113	121	118	37	L,*** G†
Night	99	106	101	96	108		

[a,b]Within a row, adjusted means values with different superscripts are different ($P < 0.05$).
[1]NP = normal protein diet; LP = low protein diet; NP+ = normal protein diet plus an AA complement.
[2]Warm season: February to April 2007 and November 2007 to January 2008. Hot season: May to October 2007.
[3]RSD = residual SD.
[4]From an analysis including the effects of season (S), diet composition (D), the effect of parity (P), the effect of photoperiod (L), and the effect of batch of sows (G), and their interactions as fixed effects.
†$P \le 0.10$; *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

Irrespective of the season, the nycthemeral pattern of feed intake peaked twice daily. The first and second peaks were observed between 0300 and 0900 h and between 1500 and 2100 h, respectively (Figure 1). The size of the peak differed and the hourly feed intakes were greater ($P < 0.05$) for the warm season compared with the hot season at 0700, 0900, 1000, and 1800 h. Sows consumed proportionally approximately 45 and

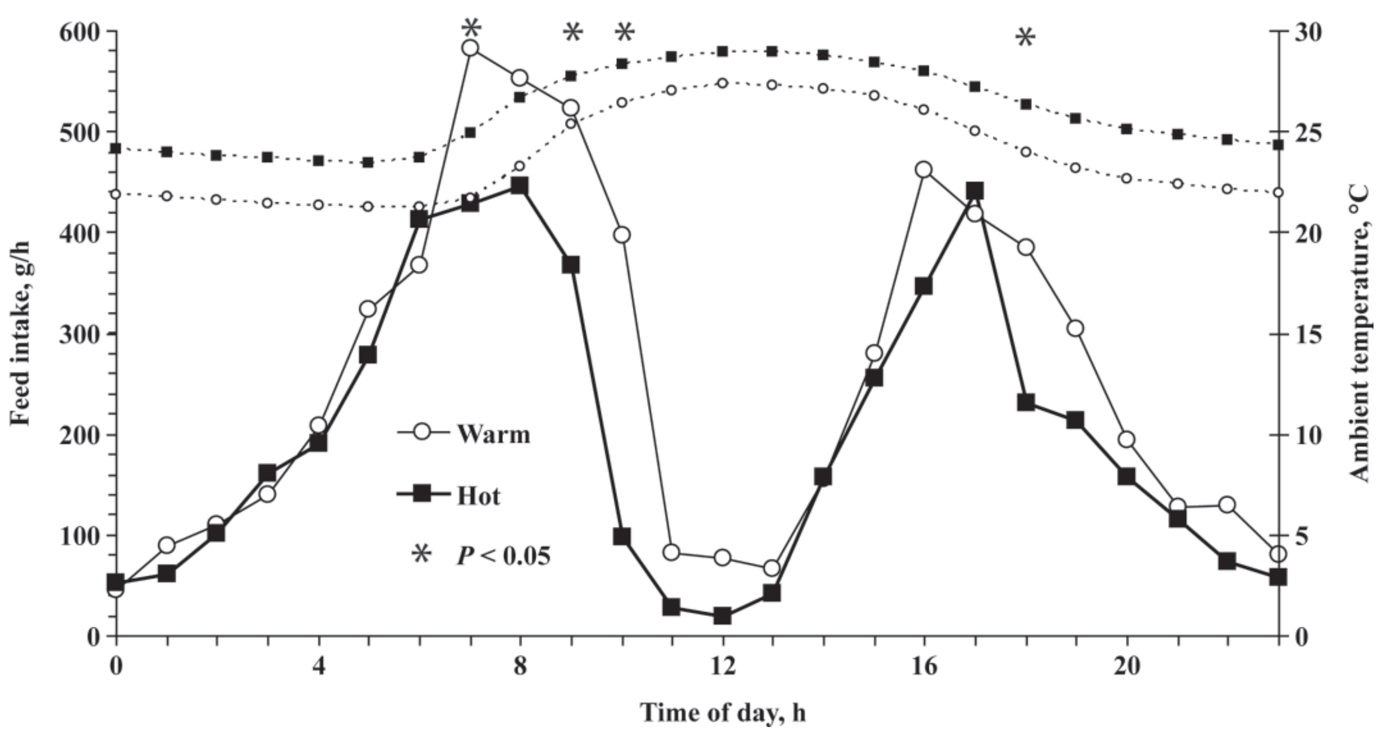

Figure 1. Effect of season and time of day on the daily fluctuations of ambient temperature (dotted lines) and daily feed intake in lactating sows (solid lines). Each point is the least squares mean of 18 sows in the warm season and 29 sows in the hot season. Asterisks indicate an effect of season ($P < 0.05$) on hourly feed consumption.

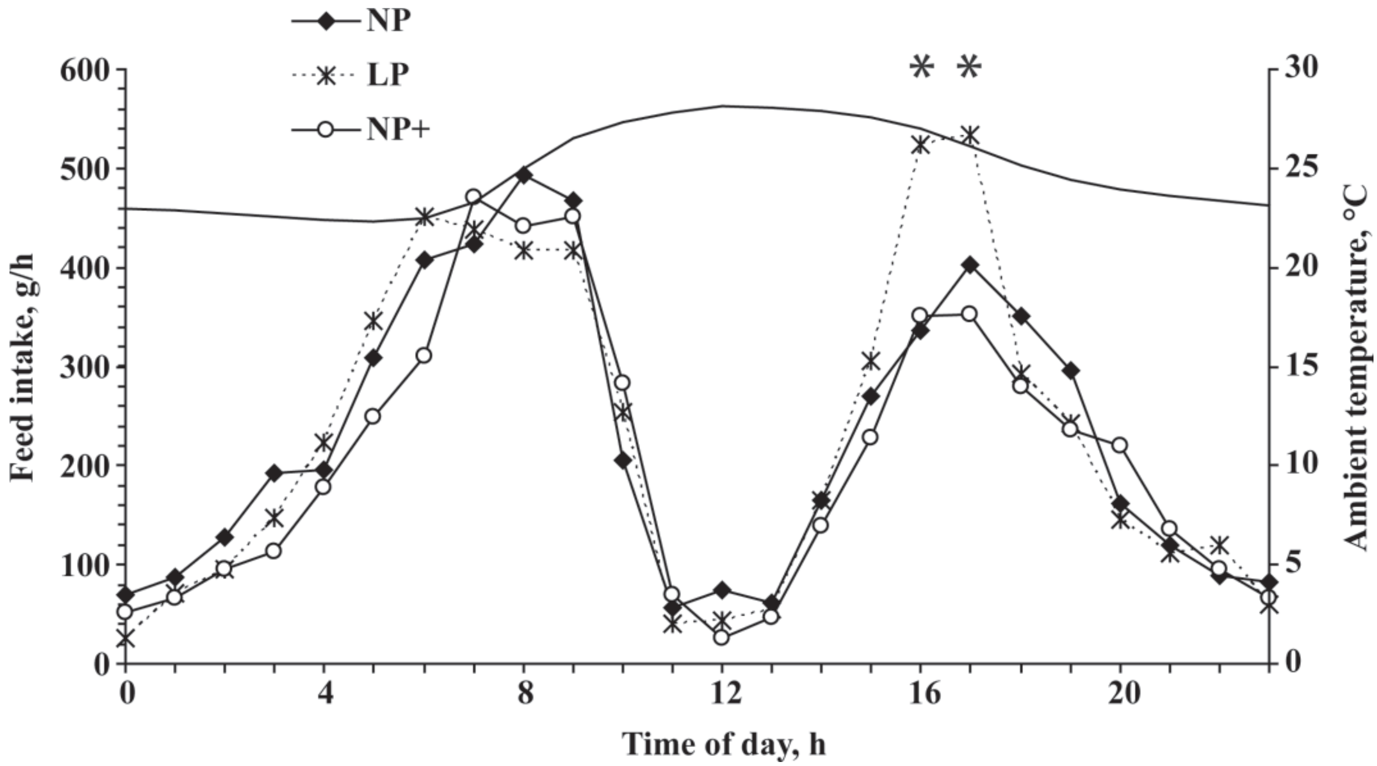

Figure 2. Effect of diet composition and time of day on daily feed intake in lactating sows. Each point is the least squares mean of 16, 16, and 15 sows fed normal protein (NP), low protein (LP), and normal protein plus an AA complement (NP+) diets. Asterisks indicate a diet effect ($P < 0.05$) on hourly feed consumption. The top solid line represents the average daily pattern of the ambient temperature.

37% of their total feed intake during the first and the second peak, respectively, for the warm and the hot season ($P < 0.05$).

The number of meals per day was not affected ($P > 0.10$) by diet composition. The average meal size was reduced by 127 g/meal in sows fed the LP diet when compared with the other 2 diets. Daily feed intake during the ad libitum period (d 6 to 26) was greater in the LP diet than in the other 2 diets (5,654 vs. 4,876 g/d). The ingestion rate was not affected ($P > 0.10$) by diet composition.

From a comparison of hourly feed intakes or variations from hour to hour (between 2400 and 0200 h), the nycthemeral pattern of feed intake peaked twice daily for all 3 dietary treatments. However, the size of the peak differed, and the hourly feed intakes were greater ($P < 0.05$) for the LP sows when compared with the other dietary treatments at 1600 and 1700 h (Figure 2).

DISCUSSION

The 47 multiparous sows used in the current study were part of a larger group of 86 mixed-parity sows for which lactation performance was studied [(B. A. N. Silva, J. Noblet, J. L. Donzele, R. F. M. Oliveira, J. L. Gourdine (INRA, Guadeloupe, French West Indies), and D. Renaudeau (unpublished data)]. For the whole lactation period, litter growth rate and ADFI recorded in the subgroup of 47 multiparous sows were comparable with the values obtained for the 86 mixed-parity sows (2.2 vs. 2.1 kg/d for litter growth, respectively; and 4.7 vs. 5.1 kg/d for ADFI, respectively). In addition, the reduction caused by the effect of season on feed intake was similar for both groups (−1.23 vs. −1.15 kg/d). According to these observations, sows used for the feeding behavior measurement were considered representative of all sows used in the study.

Effect of Season on Feeding Behavior in Lactation Sows

At constant daily temperatures in temperature-controlled rooms (Quiniou et al., 2000b; Renaudeau et al., 2002), or with experimentally generated nycthemeral fluctuations of daily temperature (Quiniou et al., 2000a) or under naturally fluctuating temperatures (Renaudeau et al., 2003a; Gourdine et al., 2006), 2 peaks of feeding activity occur during the day. One peak is observed in the morning and the other is observed before the beginning of the night. Our results, under naturally fluctuating temperatures, agree with these observations. These observations suggest that the feeding pattern activity of lactating sows was mainly driven by light intensity changes in the farrowing room. However, other environmental factors, such as the presence of staff, the collection of refusals, and the distribution of feed were partially confounded with light intensity changes and could have either attenuated or accentuated this diurnal bimodal pattern (Renaudeau et al., 2003b). Our study also showed that feeding pattern was affected by season or, more specifically, by the daily kinetics of temperature and RH. Renaudeau et al. (2003b), who conducted a study under the same conditions as ours, observed that the reduced feed intake during the hotter period of the day was partly counterbalanced by a greater quantity of feed intake during the cooler periods of the day. During the current experiment, the sows were unable to increase nocturnal consumption. In contrast to the report of Gourdine et al. (2006), which showed that more than 50% of the total daily feed intake occurred during the nocturnal period during the hot season (64%), we observed that 44% of daily feed intake occurred during the nocturnal period and that this value was greater in the hot season than in the warm season (47%). This difference can be related to the fact that the hot season ambient temperatures during the current study were less than the ones reported by the latter authors (on average, 26 vs. 28°C), which led to better conditions for our sows to have a greater feed intake during the diurnal period (53%). These results indicate in general that climatic conditions can also influence the nycthemeral feeding pattern in lactating sows.

Based on data from the current study, each degree increase in temperature corresponded to a reduction in daily feed intake of 462 g/d. Between 25 and 27°C with a 50 to 60% RH, Quiniou and Noblet (1999) reported a reduction in feed intake equivalent to 254 g/d per degree Celsius. The greater daily feed intake reduction per degree Celsius found in our study (462 g/d per degree Celsius) can be related to the effect of the increased humidity observed during our study (85 to 98%). These results suggest that the negative effect of elevated ambient temperature may be accentuated by the increased RH in a tropical climate.

During the warm season, the daily number of meals averaged 8.1 between d 6 and d 26, which is similar to the value obtained by Renaudeau et al. (2003b) between d 6 and 27 (8.8 meals/d). However, meal size was slightly reduced in our study (649 vs. 718 g/meal). According to Renaudeau et al. (2003b) and Gourdine et al. (2006), the decrease in daily feed intake in the hot season was achieved by a reduction of meal size in our study (−215 g/meal), whereas the number of meals remained constant. No significant effect of season on the rate of feed intake was observed in the present study, which is in agreement with results obtained for sows by Quiniou et al. (2000a), Renaudeau et al. (2003b), and Gourdine et al. (2006). Subsequently, the decrease in daily feed intake in the hot season was associated with a reduced ingestion time (55.8 vs. 45.5 min/d, respectively, for the warm and the hot season).

Effect of Dietary Treatment on Feeding Behavior in Lactating Sows

Whatever the season considered, except for daily feed intake and meal size, diet composition did not affect the other feeding behavior components. It did not affect sow and litter performance, which is in agreement with the results reported by Renaudeau et al. (2002). The greater daily feed intake observed for the sows fed the LP diet was associated with a greater meal size when compared with the other diets. It can then be hypothesized that the LP diet reduced the thermal effect of feed and attenuated the reduction of feed intake associated with heat stress via an increase in meal size. These results agree with the report of Renaudeau et al. (2002), who found a greater meal size for the sows fed the LP diet when compared with sows fed a normal protein diet at 29°C (730 vs. 643 g/meal, respectively). According to the thermostatic theory of feed intake regulation, body temperature is involved in the termination of a meal (De Vries et al., 1993). In other words, meal duration depends of the related magnitude of body temperature increase. According to the fact that the rate of feed intake is not affected by dietary treatment, these results suggest that the larger meal size in LP could be related to less heat increase.

The greater feed intake for LP sows was explained by an increase in feed consumption during the second peak of feeding. In the afternoon, the feed consumption seemed to be limited by the ambient temperature combined with increased RH. A decrease in dietary heat when using the LP diet could have led to an increase in feed consumption. In contrast, sows fed the NP and NP+ diets were not able to compensate for feed intake during the afternoon because of the limiting effects of the greater heat increase from the diet.

In our experimental conditions, the tryptophan:large neutral AA (**LNAA**) ratio was quite similar between the NP and NP+ diets. This effect could explain why AA supplementation did not affect feeding behavior. To our knowledge, little has been published on the effect of AA supplementation on the feeding behavior of lactating sows. An increased ratio of tryptophan:LNAA has been reported to increase the appetite linearly (Henry et al., 1992; Henry and Séve, 1993). Trottier and Easter (1995) reported that a reduction in the tryptophan:LNAA ratio according to a dietary addition of LNAA decreased the feed intake of lactating sows.

Concluding Remarks

The present study confirms that in tropical conditions, climatic factors, specifically heat and RH, limit the performance and voluntary feed intake of lactating sows. Moreover, the results suggest that lactating sows alter their feeding pattern during the hot season to attenuate the effects of elevated temperature and increased RH. Irrespective of season, reducing dietary CP can attenuate the effect of heat stress on feed intake via an increase in meal size. From these results, further studies are required to evaluate the effects of such nutritional strategies in primiparous lactating sows under tropical climatic conditions.

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