BRUNO ALEXANDER NUNES SILVA

EFFECTS OF NUTRITIONAL AND/ OR ENVIRONMENTAL MODIFICATIONS ON THE PERFORMANCE OF LACTATING SOWS AND THEIR LITTERS UNDER TROPICAL CLIMATIC CONDITIONS

Thesis presented to the Universidade Federal de Viçosa, as part of the requirements of the Post Graduation Program in Animal Science, for obtaining the title of "Doctor Scientiae".

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Thesis presented to the Universidade Federal de Viçosa, as part of the requirements of the Post Graduation Program in Animal Science, for obtaining the title of "Doctor Scientiae".

APPROVED: October 2nd of 2008.

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This thesis is dedicated...

To the great love of my life, Fernanda,

To my parents, Aluízio and Menna,

To my sister, Nicolle,

To my grandmother Maria and grandfather Eurico, in memory,

To all my family and friends.

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BIOGRAPHY

BRUNO ALEXANDER NUNES SILVA, son of Aluízio Laércio Silva and Menna Nunes Silva, born in Juiz de Fora, MG, Brazil, on the 1st of June of 1980.

In March of 1998, initiated at the Universidade Federal de Viçosa (UFV - Brazil) the course in Animal Science and concluded in March of 2003.

In August of 2003, began the MSc studies in Animal Science, in the area of Animal Bioclimatology, at the UFV, submitting the thesis on the 18th of February of 2005.

In March of 2005, began the PhD studies in Animal Science, in the area of Animal Bioclimatology and Pig Nutrition, at the UFV and partially (one year) at the Institut National de la Recherche Agronomique (INRA – France), submitting the thesis on the 2nd of October of 2008.

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RESUMO

SILVA, Bruno Alexander Nunes, D.Sc., Universidade Federal de Viçosa, Outubro de 2008. **Efeitos de modificações nutricionais e/ ou ambientais sobre o desempenho de porcas lactantes e suas leitegadas sob condições de clima tropical.** Orientadora: Rita Flávia Miranda de Oliveira. Co-Orientadores: Juarez Lopes Donzele e Haroldo Carlos Fernandes.

Duzentos e cinquenta e duas porcas Large White foram usadas em três experimentos para se avaliar os efeitos, do resfriamento do piso e o uso de dietas com diferentes concentrações de aminoacidos industriais sobre o desempenho e o comportamento das mesmas durante o verão; das dietas com redução do conteudo de PB ou suplementadas com AA industriais sobre o desempenho durante a lactação sob condições de clima tropical umido; e das dietas com redução do conteudo de PB ou suplementadas com AA essenciais sobre o comportamento alimentar durante a lactação sob condições de clima tropical umido. No primeiro experimento, as porcas foram distribuidas ao acaso em um fatorial 2 × 2 (com e sem piso resfriado × duas dietas) com 16 porcas por tratamento, sendo cada porca considerada uma unidade experimental (60 no total). Quatro repetições de 16 porcas cada foram usados durante o experimento com o objetivo de avaliar os efeitos do resfriamento do piso e o uso de dietas com diferentes concentrações de aminoacidos industriais sobre o desempenho e o comportamento das mesmas durante o verão. As porcas foram distribuidas entre os tratamentos de acordo com o peso corporal e a espessura de toucinho ao parto. As duas dietas forneceram os mesmos niveis de proteina bruta (PB; 22%), e energia metabolizavel (EM; 14,65 MJ/kg), e niveis de AA essenciais relativo a lisina digestivel e diferiram na relação da lisina digestivel com a EM (0,75 vs. 0,82 g/MJ de EM). No segundo experimento, dez repetições de oito a dez porcas Large White de diferentes ordens de parto foram usadas (89 no total). Dentro de cada repetição, as porcas foram distribuidas

em um delineamento experimental inteiramente casualizado entre três tratamentos de acordo com espessura de toucinho, ordem de parto e peso corporal apos o parto. Os tratamentos experimentais foram assim constituidos: portein normal (PN; 17,3%), baixa proteina (BP; 14,1%) e a dieta PN suplementada com um complemento de aminoacidos (PN+; 17,6%). No terceiro experimento, um total de 47 porcas multiparas, Large White, foram usadas em 10 repetições sucessivas de oito a dez animais. Dentro de cada repetição, as porcas foram distribuidas em um delineamento experimental inteiramente casualizado com três tratamentos de acordo com espessura de toucinho, ordem de parto e peso corporal apos o parto. Os tratamentos experimentais foram assim constituidos: protein normal (PN; 17,3%), baixa proteina (BP; 14,1%) e a dieta PN suplementada com um complemento de aminoacidos (PN+; 17,6%). Baseado nas temperaturas minimas e maximas obtidas durante os experimentos, podemos inferir que as porcas estiveram expostas a periodos de estresse por calor. No primeiro experimento foi concluido que o resfriamento sob a porca aumentou o consumo de ração diario (CRD) e de lisina, levando a menores perdas corporais, menor intervalo desmama-estro e tambem melhorou o comportamento de amamentação das porcas, levando a uma maior produção de leite e, consequentemente, maiores ganhos de peso dos leitões e da leitegada durante o periodo de lactação. Para o segundo experimento foi concluído que a estação quente em climas tropicais e umidos, que combina alta temperatura e umidade, tem um importante impacto negativo sobre o desempenho de porcas lactantes. Dietas com baixa PB ou suplementadas com AA industriais podem atenuar os efeitos da estação quente e umida através do aumento do CRD e reduzindo a perda de massa corporal das porcas lactantes. No terceiro experimento confirmou-se que ocorrem alterações no padrão alimentar durante a estação quente como forma de atenuar os efeitos da temperatura elevada e da alta umidade. Independente da estação, a redução no conteudo de proteina pode atenuar os efeitos do estresse sobre o consumo de ração através do aumento do tamanho da refeição.

ABSTRACT

SILVA, Bruno Alexander Nunes, D.Sc., Universidade Federal de Viçosa, October of 2008. **Effects of nutritional and/ or environmental modifications on the performance of lactating sows and their litters under tropical climatic conditions.** Adviser: Rita Flávia Miranda de Oliveira. Co-Advisers: Juarez Lopes Donzele and Haroldo Carlos Fernandes.

Two hundred and fifty two Large White sows were used in three experiments to evaluate, the effects of floor cooling and the use of dietary amino acid contents on their performance and behaviour during summer; the effect of diets with reduced CP content or supplemented with essential AA on 28-d lactation performance under humid tropical climatic conditions; and the effect of diets with reduced CP content or supplemented with essential AA on 28-d lactation feeding behaviour under humid tropical climatic conditions. In the first experiment, the sows were distributed in a completely randomized 2 × 2 (with and without floor cooling × two dietary treatments) factorial design with 16 sows per treatment, each sow being considered as an experimental unit (60 in total) according to backfat thickness, parity order and BW after farrowing. Four replicates of sixteen sows each were used during the trial. The two experimental diets supplied the same levels of crude protein (22%), metabolizable energy (ME; 14.65 MJ/kg) and levels of essential digestible AA relative to digestive lysine and differed according to the digestible lysine to ME ratio (0.75 vs. 0.82 g/MJ of ME). In the second experiment, ten successive replicates of eight to ten mixed-parity Large White sows (89 in total) were used. Within each replicate, sows were distributed in a completely randomized experimental design between three 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 amino acid (AA) complement (NP+; 17.6%). In the third experiment, a total of 47 multiparous Large White sows in a 10 successive replicates of eight to ten animals were used. Within each replicate, sows were distributed in a completely randomized experimental design between three 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 amino acid (AA) complement (NP+; 17.6%). Based on the average minimum and maximum temperatures obtained during the 1^{fst}, 2^{nd} and 3^{rd} experimental trials, it can be assumed that the sows were exposed to periods of heat stress. In the first trial it was concluded that floor cooling under the sows increased daily feed intake and lysine intake, leading to a lower body weight loss, a lower weaning-to-oestrus interval and also improved nursing behaviour of the sows, leading to a higher milk production and, consequently, higher weight gains of piglets and litter during the lactation period. For the second trial it was concluded that the hot season in humid tropical climates, which combines high levels of temperature and humidity, has an important negative impact on performance of lactating sows. Diets with low CP content or supplemented with essential AA can attenuate the effects of hot and humid season by increasing ADFI and reducing BW loss in lactating sows. In the third trial it was confirmed that changes in the feeding pattern occur during the hot season in order to attenuate the effect of elevated temperature and high relative humidity on these changes. Irrespective of season, the reduction of crude protein content can attenuate the effect of heat stress of feed intake via an increase of meal size.

INTRODUCTION

Over the last decade, pig production in tropical and subtropical countries has increased rapidly due to increased population, the consumer's rising income and, in some countries, availability of local feed ingredients (Delgado et al., 1999). Despite many challenges faced by pig industries in developing countries including price of imported raw materials, economical crisis, environmental problems, it is still predicted that pig production in these areas will continue to sustain future world growth of pig production.

In these regions, production and performance remain generally lower than those obtained in temperate countries in Western Europe and North America. Although many factors can be involved, climatic factors are the first most limiting factors of production efficiency in these warm regions. While heat stress is only an occasional challenge during summer heat waves in temperature climate, it is a constant problem in many tropical and subtropical areas. In addition, in these regions, the effects of high ambient temperature can be accentuated by a high relative humidity (Morrison et al., 1968).

Under heat stress, pigs reduce their appetite in order to reduce their heat production due to the thermic effect of feed (TEF). This reduction of feed intake is dependent on animal related factors such as BW, breed and sexual type and environmental factors such as housing, feeding and the climatic conditions. The reduction of feed consumption results in a decrease of growth of pigs and reproductive performance of sows which affects the profitability of the swine producers. Moreover, the heat stress related problems are emphasized in modern strains of pigs with a high level of growth or reproductive potential (Nienaber et al., 1997).

Due to the recognition that heat stress is a problem for pig production efficiency in geographical high temperatures regions, the objectives of many research trials in recent years has been to develop solutions to alleviate the negative effects of heat stress. Several management techniques have been tested but only a few ones were found effective and economical in minimizing the impact of heat stress in pig production. These solutions include management strategy to reduce the building ambient temperature (fan, evaporative cooling system) and/or to increase animal heat losses (floor cooling, drip cooling, snout cooling) (McGlone et al., 1988; Silva et al., 2006). According to the fact that management strategies are usually expensive, not economically feasible in most cases particularly in many tropical small scale producers, nutritional strategies are alternative techniques that can be recommended to minimize the negative effect of heat stress. It can be hypothesized that low CP diets should attenuate the reduction of feed intake associated with heat stress. Practically, CP is partially replaced by starch and/or fat and industrial amino acids in order to meet the protein requirement for optimal performance.

The voluntary feed intake related to maintenance requirement is much higher in lactating sows than in growing pigs in connection with the high requirement for milk production. As a consequence, the potential gain in using low increment diets under hot conditions should be increased in lactating sows. In comparison to growing pigs, few studies are available on the effect of low-CP diets on performance of lactating sows exposed to heat stress. In response to a reduced protein level from 16.8 to 14.3%, Quiniou and Noblet (1999) reported no improvement of performance in lactating sows housed at 29°C. Johnston et al. (1999) observed an increase in litter BW gain (+60 g/d) in hot season for mixed parity sows fed a low CP diet (13.7 vs. 16.5%). In this study, the increase of daily weight gain of litter was attributed to an increase of sow body reserves mobilization due to a probable imbalance of some essential AA (threonine, tryptophan, and valine) in LP diet. Renaudeau et al. (2001) showed a numerical increase of about 8 MJ in daily NE intake and a decrease of 30 % of BW loss in multiparous sows kept at 29°C using a diet with a combined reduced CP level (17.6 to 14.2 %) and increased fat content (+4%).

The increase of the dietary nutrient density in the diet could also be a good alternative for alleviating the depressed feed consumption and performance in pigs maintained in hot conditions. The increase of dietary energy and/or protein contents can compensate the reduced feed intake in pigs reared under hot conditions. Nutritional solutions can mainly be described according to their ability to reduce dietary heat increment or to increase dietary nutrient density. Therefore, the objectives of this study is focusing on the modification of nutritional and/ or environmental strategies to alleviate the detrimental effects of heat stress on lactating sows and their litters performance in tropical climatic conditions.

The following chapters here presented in this thesis, were edited based on the format requirements of Livestock Science Journal and Journal of Animal Science, and adapted to the norms for elaboration of thesis proposed by the Universidade Federal de Viçosa.

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Effect of floor cooling and dietary amino acids content on performance and behaviour of lactating primiparous sows during summer

Abstract - Fifty nine primiparous sows PIC Camborough 23 were distributed in a completely randomized 2 × 2 (with and without floor cooling × two dietary treatments) factorial design with 16 sows per treatment, each sow being considered as an experimental unit. Four replicates of sixteen sows each were used during the trial with the objective of evaluating the effects of floor cooling and the use of dietary amino acid contents on their performance and behaviour during summer. The sows were distributed among the treatments according to body weight and backfat thickness after farrowing. The sows were maintained in the experiment until weaning at 21 days of lactation. The two experimental diets supplied the same levels of crude protein (22%), metabolizable energy (ME; 14.65 MJ/kg) and levels of essential digestible AA relative to digestive lysine and differed according to the digestible lysine to ME ratio (0.75 vs. 0.82 g/MJ of ME). The temperature of the water circulating in the cooled floor was maintained at about 17 °C. Based on the average minimum and maximum temperatures (21.5 and 29.5 °C) obtained during the experimental trial, it can be assumed that the sows were exposed to periods of heat stress. The replicate and the interaction between replicate and treatment effects on all the measurements were not significant. Similarly, no effect of diet or interaction between diet and floor cooling system was found for all criteria measured. An effect ($P < 0.05$) of floor cooling on average daily feed intake was observed and floor cooling sows showed a higher average ($P < 0.05$) digestible lysine (61.5 vs. 51.8 g/d) and ME (78.2 vs. 65.9 MJ/d) intakes. The sows submitted to floor cooling showed, consistently, higher absolute values for average weight (+8.5 kg) and backfat (+0.75 mm) at weaning, compared with the control sows. The sows submitted to the cooled floor showed a shorter ($P < 0.05$) weaning-to-oestrus interval. The piglet and litter's daily weight gain (DWG), average weight at weaning (AWW) and total weight gain during lactation (TWG) were higher ($P < 0.05$) for the floor cooling sows. The floor cooling sows showed a higher ($P < 0.05$) daily milk production. The respiratory rate and rectal temperature values were lower ($P < 0.05$) for the floor cooling sows. There were differences ($P < 0.05$) on the cutaneous temperatures measured on the different parts of the sow's body, with the animals submitted to the cooled

floor having lower values. The sows submitted to floor cooling spent less ($P < 0.05$) time in lateral recumbency inactive, more time nursing ($P < 0.05$) and more time feeding ($P < 0.05$) compared with control sows. The floor cooling under the sows increased daily feed intake and lysine intake, leading to a lower body weight loss, a lower weaning-to-oestrus interval and also improved nursing behaviour of the sows, leading to a higher milk production and, consequently, higher weight gains of piglets and litter during the lactation period.

Efeito do resfriamento do piso e da concentração aminoacidica sobre o desempenho e o comportamento de porcas primiparas em lactação durante o verão

Resumo – 59 porcas primiparas PIC Camborough 23 foram distribuidas ao acaso em um fatorial 2 × 2 (com e sem piso resfriado × duas dietas) com 16 porcas por tratamento, sendo cada porca considerada uma unidade experimental. Quatro repetições de 16 porcas cada foram usados durante o experimento com o objetivo de avaliar os efeitos do resfriamento do piso e o uso de dietas com diferentes concentrações de aminoacidos industriais sobre o desempenho e o comportamento das mesmas durante o verão. As porcas foram distribuidas entre os tratamentos de acordo com o peso corporal e a espessura de toucinho ao parto. As porcas foram mantidas no experimento até o desmame aos 21 d de lacatação. As duas dietas forneceram os mesmos niveis de proteina bruta (PB; 22%), energia metabolizavel (EM; 14,65 MJ/kg) e niveis de AA essenciais relativo a lisina digestivel e diferiram na relação da lisina digestivel com a EM (0,75 vs. 0,82 g/MJ de EM). A temperatura da agua circulada dentro do piso resfriado foi mantida em torno de 17 °C. Baseado nas temperaturas minimas e maximas (21,5 e 29,5 °C) obtidas durante o experimento, podemos assumir que as porcas estiveram expostas a periodos de estresse térmico. Os efeitos da repetição e da interação entre repetição e tratamento sobre todos os paramêtros avaliados não foram significativos. Similarmente, nenhum efeito da dieta ou interação entre dieta e piso resfriado foi encontrado para todos os critérios medidos. Foi observado efeito ($P < 0,05$) do resfriamento do piso sobre o consumo diario de ração onde as porcas submetidas ao piso resfriado mostraram em média um maior consumo ($P < 0,05$) de lisina digestivel (61,5 vs. 51,8 g/d) e EM (78,2 vs. 65,9 MJ/d). As porcas submetidas ao piso resfriado mostraram, consistentemente, maiores valores absolutos para peso médio (+8,5 kg) e espessura de toucinho (+0,75 mm) ao desmame, comparado com as porcas do controle. As porcas submetidas ao piso resfriado apresentaram um intervalo desmama-cio mais curto ($P < 0,05$). O ganho diario do leitão e da leitegada (GD), peso médio ao desmame (PMD) e o ganho total de peso (GTP) foram maiores ($P < 0,05$) para as porcas do piso resfriado. As porcas do piso resfriado mostraram uma maior($P < 0,05$) produção de leite diaria. Os valores de frequência respiratoria e temperatura retal foram menores ($P < 0,05$) para as porcas do piso resfriado. Foram observados diferenças ($P < 0,05$) nas temperaturas cutaneas avaliadas nas diferentes partes do corpo das porca, com os animais submetidos ao resfriamento de piso apresentando valores menores. As porca submetidas ao

piso resfriado apresentaram menos tempo ($P < 0,05$) deitadas lateralmente inativas, mais tempo amamentando ($P < 0,05$) and mais tempo alimentando ($P < 0,05$) comparado com as porcas do tratamento controle. O resfriamento sob a porca aumentou o consumo diario de ração e de lisina, levando a menores perdas corporais, menor intervalo desmama-estro e tambem melhorou o comportamento de amamentação das porcas, levando a uma maior produção de leite e, consequentemente, maiores ganhos de peso dos leitões e da leitegada durante o periodo de lactação.

Introduction

In tropical conditions, the thermal discomfort is constant in pig farms and represents one of the main factors that affect performance. In this context, an appropriate managing of lactating sows during heat stress is essential for the pig industry. Lactating sows exposed constantly to high temperatures associated to high relative humidity reduce their voluntary feed intake in order to reduce heat production due to the thermic effect of feed (Renaudeau et al., 2005). Milk production is also reduced. However, the reduction in energy intake is more important when compared to the change in energy requirements due to decreased milk production capacity, which results in an accentuated nutritional deficit and an increased body reserve mobilization (Renaudeau et al., 2001). Additionally, the low level of daily feed intake during lactation is shown to delay the return to oestrus, decrease conception rates, and increase embryo mortality (Quiniou et al., 2000; Diehl and Albrecht, 2001; Renaudeau et al., 2003). These effects can be more accentuated in primiparous sows, as these animals have a lower feed intake capacity (Young et al. 2004) and the increase of ambient temperature above the thermal neutral zone (i.e. above 18-20 °C) can then compromise more the primiparous than the multiparous sows. Performance of lactating sows exposed to tropical climate conditions can be maintained by increasing heat loss to the environment (Quiniou and Noblet, 1999). Thus, reducing the effects of heat stress on the lactating sow can be favourable for the performance of both sow and litter (Silva et al., 2006).

Some alternatives can minimize the negative effects of high temperatures inside the farrowing house. An alternative approach is to increase heat loss of the sows using cooling systems inside the farrowing room (Stansbury et al., 1987; McGlone et al., 1988; and Silva et al., 2006). Nutritional solutions can also be used to alleviate the negative consequences of heat stress on the sows performance. The increase of dietary nutrient density (i.e., increasing amino acid content in the diet) could be an alternative to compensate the depressed feed consumption in sows maintained in hot conditions (Renaudeau et al., 2008). Based on these considerations, this study was realized with the purpose of evaluating the effects of floor cooling and the use of two dietary amino acid contents on the performance and behaviour of lactating primiparous sows in summer under Brazilian climatic conditions.

Materials and methods

Experimental design

The experiment was conducted during summer period at the farrowing houses of Pig Breeding sector of the Department of Animal Science at Federal University of Viçosa, Viçosa, Minas Gerais, Brazil. The municipality is located in a tropical climate region (20º 45’ 45”S and 4º 52’ 04”W, with an altitude of 657 m).

Sixty four PIC Camborough 23 primiparous sows were used in this experiment in four replicates of sixteen animals between January and May of 2006. Within each replicate, the animals were moved to two similar farrowing houses in two batches of 8 sows each and distributed in a completely randomized experimental design in a factorial 2 × 2 (with and without floor cooling × two dietary treatments) with 16 sows per treatment, each sow being considered as an experimental unit. The sows were distributed among the treatments according to body weight and backfat thickness after farrowing. The sows remained in the experiment from farrowing to weaning at 21 days of lactation.

The basal diet was formulated with maize, soybean meal, soybean oil and supplemented with minerals and vitamins to achieve the requirements for this animal category defined by Rostagno et al. (2005). The high amino acids (AA) density diet was supplemented with synthetic AA (lysine, threonine, and methionine) (Table 1). The two experimental diets supplied the same levels of crude protein (22%), metabolizable energy (ME; 14.65 MJ/kg) and levels of essential digestible AA relative to digestible lysine. The experimental diets differed according to the digestible lysine to ME ratio (0.75 vs. 0.82 g/MJ of ME). Composition of the diets is given in Table 1.

Animal handling

During the gestation period, the primiparous sows received the following feed management. From insemination to day 96 of gestation, all sows were fed 2.6 kg/d of a standard gestation diet containing 14% crude protein (CP), 0.72% total lysine and 12.8 MJ/kg ME. As the experimental diets used during the trial had high levels of CP and ME, a transition diet was used between day 96 and 114 of gestation when sows received 2.7 kg/d of a lactation diet containing 19% CP, 1.1% total lysine and 13.6 MJ/kg of ME.

Table 1 - Composition of the lactation diets

Ingredients (%)	Basal	High AA
Maize	49.70	49.45
Soybean meal	39.87	39.87
Soybean oil	7.10	7.10
L-lysine	-	0.14
L-threonine	-	0.07
DL-methionine	-	0.04
Dicalcium phosphate	1.81	1.81
Limestone	0.67	0.67
Mineral mix[1]	0.20	0.20
Vitamin mix[2]	0.20	0.20
BHT (beta hydroxytoluene)	0.01	0.01
Salt	0.44	0.44
Analyzed chemical composition (as fed, %)		
Crude protein	22.2	22.3
Total lysine	1.23	1.34
Digestible lysine	1.10	1.21
Digestible methionine + cysteine	0.62	0.66
Digestible threonine	0.74	0.82
Digestible tryptophan	0.24	0.24
Digestible valine	0.93	0.93
Calcium	0.85	0.85
Available phosphorus	0.45	0.45
Digestible lysine, g/ MJ of ME	0.75	0.82
ME, MJ/ kg	14.65	14.65

[1] Mineral mix contains/kg: 100 mg iron, 10 mg copper, 1 mg cobalt, 40 mg manganese, 100 mg zinc, 1.5 mg iodine, and vehicle qsp.
[2] Vitamin mix contains/kg: 8000 IU vitamin A, 1200 IU vitamin D3, 20 IU vitamin E, 2 mg vitamin K3, 1 mg vitamin B1, 4 mg vitamin B2, 22 mg nicotinic acid, 16 mg pantothenic acid, 0.50 mg vitamin B6, 0.020 mg vitamin B12, 0.4 mg folic acid, 0.120 mg biotin, 400 mg choline, and 30 mg antioxidant.

At d 110 of gestation, the sows were moved to the farrowing houses, where they were allocated individually in farrowing crates until weaning. Sows were fed ad libitum after farrowing and water was available through a low pressure nipple drinker.

The piglets were handled (tooth and tail cutting, umbilical cord treatment, labelling and antibiotic administration) up to 24 h after birth and the litter was equalized to 10 piglets until the end of the second day after farrowing. At day 10, males were castrated. During the lactation period, piglets had no access to creep feed or to the sow feed but water was available *ad libitum* through a low pressure nipple drinker.

At weaning, the piglets were moved to the nursery of the farm, and sows were moved to a breeding facility and checked twice daily for signs of oestrus using a mature boar. Oestrus was recorded when sows stood to be mounted by the boar.

Equipment and installations

The sows were individually housed in open fronted farrowing pens (2.0 m × 1.60 m) separated by brick walls. The floor consisted of solid concrete almost throughout the cage, except for the part of the gutter (0.25 m × 1.50 m × 0.40 m) which was protected with an iron lattice-covered floor at the back of the cage. Each pen was equipped with a semiautomatic feeder and a drinker for the sows and an infrared light to provide supplemental heat for the piglets. No bedding material was used. Variations in ambient temperature, relative humidity, and photoperiod closely followed outdoor conditions.

The temperature of the water circulating in the cooled floors under the sows was maintained at about 17 °C (+/-) by using a cooling compressor motor (Model FF 8.5 BKW Embrako – ¼ HP, Brazil) unit connected to a thermal box (capacity for 450 l of water). A detailed description of the system to realize the floor cooling was previously given (Silva et al., 2006).

Measurements and parameters analyzed

The sows were weighed up to 24 h after farrowing and at weaning. Backfat thickness was measured at the same times by ultrasound (Model Microem MTU 100, Brazil). Two measurements were made 6.5 cm from the dorsal midline on the right and left side of the animal at the level of the 10th rib (P2), and the mean obtained for the two sides was considered for analysis. Piglets were individually weighed at birth and at weaning.

The thermal environment inside the farrowing house was monitored daily 5 times a day (07:00, 09:30, 12:00, 14:30 and 17:00 h) using minimum and maximum, dry and wet bulb, and black globe thermometers (Incoterm Ind. de termometros LTDA, Porto Alegre, RS, Brazil). These data were then converted to the black globe humidity index (BGHI), to characterize the thermal ambient of the sows, using the equation proposed by Buffington et al. (1981). During the experimental period, rectal temperature was measured twice a day (09:00 and 15:00 h) at 4-d intervals using a digital thermometer. The respiratory rate was determined for 1 min on the same days and at the same times by counting the movements of the flank only on quiet animals. Floor and surface temperatures (neck, hind thigh and chest) of the sows were also measured on the same days and at the same times with a laser thermometer (Model Raytec Minitemp MT4, São Paulo, Brazil). The surface temperatures in contact with the floor and the floor temperature were measured immediately after the lying sow was lifted up.

Twenty eight sows were used for the behavioural observations on the lactating sows which were realized by using video cameras. Four periods of observations per batch were realized at d 2, 7, 14 and 20 of lactation. The image recordings were realized during a period of 24 h. The following sow behaviours were recorded: feeding, standing but not feeding (inactive, rail biting, etc.), sitting, and in lateral recumbency nursing.

Feed was analyzed for moisture, ash, N, and fat according to the methods of Silva and Queiroz (2004), at the Laboratory of Animal Nutrition, Department of Animal Science, Federal University of Viçosa, Brazil.

Calculations and statistical analyses

The daily maximum, minimum and mean values of ambient temperature, relative humidity and black globe humidity index were averaged for each replicate. Changes in body weight (BW) and backfat thickness during lactation were calculated from BW and backfat thickness at weaning and farrowing. From these values, changes in body protein content (BPC) and fat content (BFC) were calculated using the equations proposed by Whittemore and Yang (1989) and Clowes et al. (2003), respectively. The milk production was estimated for the whole lactation period from litter size and piglet average daily BW gain (g/d) using the equation of Noblet and Etienne (1989). The ME for milk production and total energy requirements was calculated using the equations proposed by Noblet et al. (1990). Feed intake was determined as the difference between feed allowance and the refusals collected on the next morning between d 1 after farrowing and d 21 at weaning.

Body surface temperatures and rectal temperature measurement made at 09:00 h and 15 00 h were averaged per sow for the whole lactation period. Similar calculations were done for floor temperature data. Behavioural activities of sows were obtained from the average of four observations (at d 2, 7, 14 and 20 after farrowing) of each replicate and expressed in minutes per sow during a 24-h period.

The data on daily feed intake, body weight and backfat thickness variation, weaning-to-oestrus interval, behaviour activities and milk production of the sows, as well as the piglets performance data where statistically analyzed according to linear models using the ANOVA procedure associated to Newman-Keuls test of SAEG (SAEG, System for Statistical and Genetic Analyses, 2000) with replicate, diet composition, floor cooling and interactions as main effects. The litter and the average piglet BW were used as covariates to analyse the effect of the experimental treatment on litter and piglet BW gain from d1 to weaning. The BW and backfat thickness of the sows at farrowing were used as covariates to analyse BW, protein, and fat changes during lactation. The ANOVA procedure associated to Tukey test of SAEG was used to analyse the effects on the physiological parameters with replicate, diet composition, floor cooling and interactions as main effects.

Results

Because of low litter size (< 8 piglets) and health problems, four sows were removed from the study. Actual maximum and minimum temperatures, relative humidity and black globe humidity index averaged 29.5 and 21.5, 64.9%, and 76.6 during the experiment (Table 2). The replicate effect and the interaction between replicate and treatment effects on all the measurements were not significant. Similarly, no interaction between diet and floor cooling system was found for all measured criteria.

Although the AA levels had no significant influence ($P > 0.05$) on feed intake, the feed consumption of high AA diet was numerically lower than with the control diet (- 7% on average). The lactation BW and backfat losses were not influenced by an increase of AA dietary content (8.4 kg and 1.6 mm on average). Similarly, litter BW gain, milk production and physiological parameters were maintained constant for the two dietary treatments.

According to the design of the trial, no difference in postpartum body weight, body fat and protein contents, as well as backfat thickness of the sows was observed among treatments. The average daily feed and ME intakes increased significantly when the floor was cooled (+ 15.7%, on average; table 3). The floor cooling had no effect ($P > 0.05$) on backfat thickness, and body protein and fat contents at weaning. Although there was no significant difference, the floor cooled sows showed higher absolute values for average body weight (+ 8.5 kg), backfat thickness (+ 0.75 mm); and body protein (+ 1.5 kg) and fat (+ 2.8 kg) contents at weaning. The sows body weight loss during lactation was lower ($P < 0.05$) in the floor cooled sows either in absolute (6 vs. 12 kg) or relative (2.7 vs 5.9%)

Table 2 - Average maximum, minimum and dry bulb (DBT) temperatures, relative humidity (RH) and black globe humidity index (BGHI) during the trial

Time	DBT (ºC)	RH (%)	BGHI[a]
07:00 h	22.8 ± 2.11	82.6 ± 5.60	70.8 ± 2.80
09:30 h	25.6 ± 1.88	74.3 ± 9.29	73.6 ± 2.26
12:00 h	28.2 ± 2.27	65.4 ± 11.20	76.2 ± 2.53
14:30 h	29.4 ± 2.35	61.4 ± 11.26	77.5 ± 2.59
17:00 h	28.5 ± 2.56	64.9 ± 11.98	76.6 ± 2.72
Daily temperature (ºC)			
Minimum	21,5 ± 4,5		
Maximum	29,5 ± 1,1		

[a] Index proposed by Buffington et al. (1981) is calculated by the equation: BGHI=tg+0.36td+41.5, where tg=black globe thermometer temperature and td=dew point temperature. This index is used to characterize the sows' thermal environment.

values. No differences ($P > 0.05$) were found in the absolute and relative losses of backfat thickness and protein and fat contents between the cooled floor and control sows. Differences were observed ($P < 0.01$) in the weaning-to-oestrus interval, on which the sows of the cooled floor showed a shorter interval.

The results of piglets and litter body weight gains during the lactation period are shown in Table 4. No significant difference was observed in the litter size, piglet body weight (BW) or litter weight after crossfostering for cooled floor and control sows. Litter size at weaning was equivalent for all treatments ($P > 0.05$). The piglet's average daily weight gain (ADWG), average weaning weight (AWW) and total weight gain (TWG) during the lactation were 21.9, 17.2 and 21.3% higher ($P < 0.01$), respectively in the floor cooling sows. The treatments influenced the sows daily milk production, with the sows submitted to floor cooling showing a higher ($P < 0.01$) daily milk production.

The results of the physiological measurements and floor temperatures obtained from the sows during the lactation period are shown in Table 5. Except for the rectal, thigh and chest (without contact with floor) temperatures checked in the morning, all other physiological parameters studied were influenced by the floor cooling ($P < 0.01$). Sows submitted to floor cooling had lower ($P < 0.01$) values of respiratory frequency and floor temperature in the morning and afternoon ($P < 0.01$) and a lower rectal temperature measured afternoon ($P < 0.01$). Significantly lower surface temperatures measured in the different regions of the sow's body were observed in sows submitted to floor cooling ($P < 0.01$). The floor cooling sows had lower ($P < 0.01$) floor temperatures when compared with the control sows (i.e., 27.5 vs. 37.3°C, respectively).

The results of the sows' behaviour activities during the lactation period are shown in Table 6. The floor cooling influenced ($P < 0.01$) the behaviour of the primiparous sows, where the floor cooling sows spent less time in lateral recumbency inactive and more time nursing ($P < 0.05$) compared with control sows. The feeding activity was also influenced by the treatments, where the sows on the cooled floor spent more time feeding ($P < 0.01$).

Discussion

The effect of high ambient temperature on the performance of lactating sows is well known in the literature (Black et al., 1993) with negative effects on performance and behaviour when ambient temperature rises above the evaporative critical temperature of the sow (i.e., 22 °C, Quiniou and Noblet, 1999). Under our tropical humid conditions, the average minimum and maximum temperatures observed (21.5 ± 4.5 and 29.5 ± 1.1 °C) frequently exceeded 22 °C. Therefore, lactating sows suffered from heat stress most of the time in our experimental conditions.

Effect of Dietary Amino Acids Content on Sow and Litter Performance

In the current study, the amino acid content of the diets had no significant effect on the sows' performance and behaviour. Although the dietary lysine content had no significant influence on voluntary feed intake, the feed consumption of the high AA diet was numerically lower than for the control diet. In primiparous sows kept in the same experimental conditions than ours, Cota et al. (2003) evaluating different levels of lysine (0.95, 1.03, 1.10, 1.18 and 1.25%) obtained by adding synthetic amino acids also observed no significant difference in feed intake. Moreover, for levels of lysine content similar to the levels used in our trial, the latter authors also observed a numerically lower feed intake. Evaluating the effects of lysine levels in lactating primiparous sows, via an addition of synthetic amino acids, Tokach et al. (1992) and Paiva et al. (2005) did not observe significant effect of the levels of lysine on feed intake. In a different way, Yang et al. (2000) evaluating dietary lysine concentration obtained by an increase in protein content, on the performance of primiparous sows observed a linear decrease in voluntary feed intake with the dietary lysine increase. Unfortunately, we do not have a clear explanation for the reduction in feed intake observed for the sows fed with the high AA diet.

The sows' BW mobilization during the lactation period was not affected by the amino acid content in the diets. In agreement with our results, Cota et al. (2003) and Paiva et al. (2005), evaluating levels of lysine (obtained from synthetic amino acids) for primiparous sows in tropical climate conditions, observed similar average BW loss when comparing within similar levels of lysine that were used in our study (1.1 and 1.2% digestible lysine). Consistently, Dourmad et al. (1998), lactating normal to high-yielding primiparous sows need 45 to 55 g/d of crude lysine, for achieving a zero protein balance. The daily average lysine consumption for the basal and high amino acid content diets (56.1 and 57.3 g/d, respectively) observed in our study indicate that our lysine levels were higher than those suggested by Dourmad et al. (1998). As the AA supply at the lowest level was high in our study, therefore, it was not surprising to observe no effect of amino acid content on BW mobilization.

Similarly, litter BW gain and milk production were maintained constant according to the dietary treatment. Confirming these results, Dourmad et al. (1998), Cota et al. (2003) and Paiva et al. (2005) also did not observe effect of the lysine level on milk production. These results indicate that the sows are able to maintain their milk production using a progressive mobilization of body reserves until a determined point, when the body mobilization is not enough to maintain the production. In our study, we obtained a body mobilization of 4.5 and 4.1% for the basal and the high amino acid content diets, respectively. Clowes et al. (2003) stated that lactating sows are able to maintain their milk production until the protein mobilization is lower than 9 to 12% of their body protein content.

Effect of Floor Cooling on Sow and Litter Performance

The floor cooling treatments improved the efficiency of the sensible heat loss between the animal and the floor as a result of an increase in the temperature gradient between the sow's body and cooled floor, thus favouring homoeothermic balance.

Since an increase in the respiratory rate is one of the physiological mechanisms used by pigs to increase heat loss to the environment (Renaudeau et al., 2005), the response observed for the sows of the cooled floor would indicate that these animals were more efficient to lose heat via non evaporative losses (contact with the cooled floor) and consequently having their respiratory rate reduced.

The higher surface temperatures observed for the sows submitted to the uncooled floor are attributed to an increase in peripheral blood circulation as a way to dissipate body heat. Confirming the relationship between surface temperature and body heat loss,

Table 3 - Effect of diet amino acid level and floor cooling on performance of the lactating primiparous sows during a 21-d lactation

Variable	Treatment				*RSD*[1]	Statistical Analysis[2]
	Basal Diet		High AA			
	Uncooled floor	Cooled floor	Uncooled floor	Cooled floor		
Number of sows	14	15	15	15		
Feed intake (kg/d)	4.71[bc]	5.48[a]	4.28[c]	5.19[ab]	0.66	C**
Metabolizable energy intake (MJ/d)	69.0[bc]	80.3[a]	62.8[c]	76.1[ab]	2.3	C**
Digestible lysine intake (g/d)	51.8[b]	60.3[a]	51.9[b]	62.8[a]	7.8	C**
Sow body weight (BW, kg)						
Postpartum	200.9	205.6	199.7	200.0	10.3	
At weaning	188.7	198.7	187.8	194.8	11.7	C†, R**
BW change (kg)	-12.2[a]	-6.9[b]	-11.8[a]	-5.1[b]	8.6	C*, R**
Backfat thickness (mm) (BFT)						
Postpartum	14.7	14.9	14.7	14.7	1.2	
At weaning	12.5	12.9	12.5	13.6	1.7	R†
BFT change (mm)	-2.2	-2.0	-2.2	-1.1	1.3	C†
Body protein content (kg)[3] (BPC)						
Postpartum	32.6	33.4	32.4	32.4	1.9	
At weaning	30.7	32.6	30.6	31.7	2.1	C†, R†
BPC variation (kg)	-1.2	-0.8	-1.7	-0.7	2.2	R†
Body fat content (kg)[4] (BFC)						
Postpartum	43.9	45.2	43.6	43.7	3.2	
At weaning	38.0	40.6	37.8	40.9	4.3	C†, R†
BFC variation (kg)	-5.9	-4.5	-5.7	-2.7	3.2	C†, R†
Weaning-to-oestrus interval (days)	5,7[a]	4,0[b]	5,7[a]	4,3[b]	1.5	C**

[1] Residual standard deviation. [2] From an analysis of variance for linear models including the effects of replicate (R), floor cooling (C) and their interactions (CxR). No effect of diet or interaction between diet and floor cooling was found for all measured criteria. Statistical significance: **p<0.01, *p<0.05, †p≤0.10; [a, b, c] Within a line, means with different superscripts are significantly affected by treatment (P<0.05). [3] Body protein content (kg) considering weight and BFT at farrowing and weaning = -2.3 + (0.19 x body weight, kg) – (0.22 BFT, mm) (Whittemore e Yang, 1989; in Clowes et al., 2003). [4] Body fat content (kg) considering weight and BFT at farrowing and weaning = -20.4 + (0.21 x body weight, kg) + (1.5 BFT, mm) (Clowes et al., 2003).

Quiniou and Noblet (1999), Collin (2000) and Renaudeau et al. (2003) reported rises in the surface temperatures of lactating sows when the environmental temperature increased from 20 to 28 °C. The fact that in our study the floor cooling sows spent less time in lateral recumbency inactive compared with the control sows, reveals that the cooled floor provided more thermal comfort conditions, thus, spending more time nursing and less time inactive. Similarly to our results, Renaudeau et al (2003) observed that lactating sows under heat stress spent more time inactive than sows in thermoneutral conditions.

The floor cooling sows had lower values of rectal temperature (RT) in the afternoon when compared to that of control sows. According to literature, the RT can be assumed as the result of the entire thermoregulation process. Thus, the floor cooling sows showed a RT inside the physiological limit for this animal category (38.8 – 39.4 °C; Curtis, 1983), indicating that the floor cooling allowed an increase of the thermoregulatory responses, increasing the rate of heat loss from the body to the floor. This fact explains that the sows did not need to reduce feed intake to maintain their homeothermy.

The higher ($P<0.05$) voluntary feed intake observed for the cooled floor sows was due to the fact that the cooling of the floor improved the efficiency of the sensible heat loss between the animals and the floor as a result of an increase in the temperature gradient, thus favouring that the sows did not need to reduce their voluntary feed intake in order to maintain homoeothermic balance. Similar results were obtained with the use of drinking chilled water on the performance of lactating sows under heat stress. Jeon et al. (2006), found an increase of 40% in voluntary feed intake when sows had access to chilled water, the authors attributed this increase in the feed intake to the fact that chilled water absorbs more heat than non chilled water and, as a consequence, improving the thermoregulation process of the sows. The increase in the time spent feeding by the floor cooling sows justifies the increase observed in the daily feed intake of these animals.

The average daily weight gain (ADWG), average weaning weight (AWW) and the total weight gain (TWG) during suckling of piglets and litter were higher ($P<0.05$) in floor cooling sows. These results are attributed to the fact that the piglets from the floor cooling sows showed a higher nursing demand which consequently affected the milk production yield of the sows. The number of suckling piglets is one of the factors that can influence milk production of sows (Quesnel et al., 2007). The fact that the number of piglets did not differ among treatments excludes the possibility that this variable contributed to the difference in milk production observed the two treatments evaluated in this study.

Table 4 - Effect of diet amino acid level and floor cooling on performance of the litter during a 21-d lactation[1]

Variable	Treatment				*RSD*[2]	Statistical Analysis[3]
	Basal Diet		High AA			
	Uncooled floor	Cooled floor	Uncooled floor	Cooled floor		
Number of sows	14	15	15	15		
Number of piglets						
After cross fostering	10	9.8	9.8	9.9	0.1	
At weaning	9.9	9.7	9.7	9.7	0.4	
Piglet BW (kg)						
After cross fostering	1.32	1.30	1.40	1.38	0.22	
At weaning	5.33[b]	6.60[a]	5.65[b]	6.67[a]	0.93	C**
BW gain (g/d)	200[b]	264[a]	212[b]	264[a]	42	C**
Litter BW (kg)						
After cross fostering	13.2	12.8	13.8	13.7	2.2	
At weaning	53.0[b]	64.2[a]	54.8[b]	65.0[a]	9.5	C**
BW gain	39.8[b]	51.4[a]	41.0[b]	51.2[a]	8.7	C**
Weight gain (kg/d)	1.96[b]	2.57[a]	2.04[b]	2.55[a]	0.44	C**
Milk production (kg/d)[4]	7.20[b]	9.51[a]	7.53[b]	9.55[a]	1.59	C**

[1] The piglets had no access to creep feed. [2] Residual standard deviation. [3] From an analysis of variance for linear models including the effects of replicate (R), floor cooling (C) and their interactions (CxR). No effect of diet or interaction between diet and floor cooling was found for all measured criteria. Statistical significance: **p<0.01; [a, b, c] Within a line, means with different superscripts are significantly affected by treatment (P<0.05). [4] Estimated based on piglet average daily weight gain (g/ d), the average number of piglets and the milk dry matter (19%) MP (kg/ d) = ([0.718 x ADG – 4.9] x N° piglets)/ 0.19 (Noblet and Etienne, 1989).

The higher performance of the piglets observed with the reduction in floor temperature is related to the increased time that the sows spent nursing. This result evidenced that cooling the floor provides more comfort for the sows. The lactating sows maintained on cooled floor showed a total time of nursing higher than the control.

In comparison with control sows, the floor cooling increased by about 23% the milk production. It can be suggested that the increase of milk production is directly connected to an increase of nutrient available for milk production. Once the BW loss was lower in the sows submitted to the cooled floor, we can assume that the sows increased their efficiency of using energy from the feed for milk production. This suggestion can be confirmed by the fact that the increase in ME for production for the sows maintained on the cooled floor was higher than the relative ME for production for the control sows (53.5 vs. 41.4 MJ/d, respectively), this difference is related to the increase observed of the daily feed intake, excluding a possible direct effect of floor cooling on the milk production capacity. Nevertheless, we can also assume an effect of the improvement in the thermal conditions of the sows. Silva et al. (2006) evaluating the effects of floor cooling on lactating multiparous sows, observed an increase of 21% in milk production when the sows were submitted to floor cooling. According to these authors, the results obtained can be related to the improvement of thermal comfort which increased the milk production capacity, independently of the increase observed for voluntary feed intake.

The improvement in the thermal comfort proportioned better conditions for these animals to express their optimal production performance, as the excess of endogenous metabolic heat was eliminated by the contact of the mammary glands with the cooled floor, the sows showed increase in milk yield. This explanation can also be related to the fact that the floor cooling perhaps avoided that the blood flow distribution along the sows body and mammary glands was affected by the heat stress, maintaining a normal blood flow to the mammary gland parenchymas, with consequent adequate absorption of nutrients.

The higher ($P < 0.01$) voluntary feed intake observed for the cooled floor sows inferred in a lower ($P < 0.05$) body weight variation. Gourdine et al. (2006), evaluating the effect of season (hot x warm) on the performance of lactating sows in a tropical climate, observed that the decrease of the ambient temperature, providing more thermal comfort, resulted in an increase of feed intake, reducing BW mobilization in Large White sows.

Table 5 - Effect of diet amino acid level and floor cooling on average respiratory rate, cutaneous temperatures (neck, thigh and chest) and rectal temperature of the sows, and temperature of the floor under the sow[1]

Variable	Treatment				RSD^2	Statistical Analysis[3]
	Basal diet		High AA			
	Uncooled floor	Cooled floor	Uncooled floor	Cooled floor		
Number of sows	14	15	15	15		
Respiratory frequency (breaths/ min.)						
Morning	58.8^a	22.8^b	59.2^a	21.9^b	14.0	C**, R**,CxR**
Afternoon	92.4^a	33.1^b	92.1^a	33.7^b	15.5	C**
Rectal temperature (ºC)						
Morning	39.2^a	39.1^b	39.1^b	39.0^b	0.2	C**, R**,CxR**
Afternoon	39.8^a	39.1^b	39.7^a	39.2^b	0.2	C**
Neck temperature (ºC)						
Morning	37.2^a	36.5^b	37.2^a	36.2^c	0.8	C**, R**,CxR**
Afternoon	38.8^a	37.6^b	38.7^a	37.2^b	0.5	C**
Thigh temperature in contact with the floor (ºC)						
Morning	36.5^a	27.5^b	36.4^a	27.2^b	2.0	C**, R**,CxR**
Afternoon	38.6^a	29.3^b	38.4^a	29.1^b	1.6	C**
Thigh temperature without contact with the floor (ºC)						
Morning	37.6	37.2	37.5	37.3	0.8	C†, R†
Afternoon	38.8^a	38.5^a	38.9^a	38.1^b	1.2	C**, R†,CxR†
Chest temperature in contact with the floor (ºC)						
Morning	37.4^a	30.7^b	37.2^a	30.3^b	1.8	C**, R**,CxR**
Afternoon	39.4^a	32.2^b	39.1^a	32.1^b	1.5	C**, R†,CxR†
Chest temperature without contact with the floor (ºC)						
Morning	38.1	38.1	37.9	38.0	1.2	
Afternoon	39.6^a	38.9^b	39.7^a	39.1^b	0.9	C**, R**
Floor temperature under the sows (ºC)						
Morning	36.4^a	26.5^b	36.3^a	26.6^b	2.1	C**, R**,CxR**
Afternoon	38.3^a	28.7^b	38.1^a	28.5^b	1.1	C**, R**,CxR**

[1] Average of eight measurements per sow obtained during four stages of lactation (5, 10, 15 and 20 d) at 0900 and 1500. [2] Residual standard deviation. [3] From an analysis of variance for linear models including the effects of replicate (R), floor cooling (C) and their interactions (CxR). No effect of diet or interaction between diet and floor cooling was found for all measured criteria. Statistical significance: **p<0.01, *p<0.05, †p≤0.10; [a, b, c] Within a line, means with different superscripts are significantly affected by treatment (P<0.05).

Table 6 - Effect of diet amino acid level and floor cooling on primiparous sows behaviour during a 21-d lactation[1]

Variable	Treatment				RSD[2]	Statistical Analysis[3]
	Basal Diet		High AA			
	Uncooled floor	Cooled floor	Uncooled floor	Cooled floor		
Number of sows	7	7	7	7		
Sows behaviour activities (min/d)						
Nursing	61.2[b]	74.8[a]	66.3[c]	76.3[a]	3.3	C*
Lateral decumbency inactive	571.4[b]	521.8[a]	563.5[c]	520.5[a]	4.2	C**, R†
Sitting down	8.9[b]	36.7[a]	9.1[b]	38.4[a]	3.6	C*, R†
Feeding	25.2[b]	38.7[a]	23.6[b]	36.8[a]	1.9	C**
Standing (without feeding)	85.3[b]	92.8[a]	88.2[b]	94.4[a]	3.8	C*, R†

[1] Behaviour activities were obtained from the average of four observations (at d 2, 7, 14 and 20 after farrowing) of each replicate and expressed in minutes per sow during a 24-h period. [2] Residual standard deviation. [3] From an analysis of variance for linear models including the effects of replicate (R), floor cooling (C) and their interactions (CxR). No effect of diet or interaction between diet and floor cooling was found for all measured criteria. Statistical significance: **p<0.01, *p<0.05, †p≤0.10; [a, b, c] Within a line, means with different superscripts are significantly affected by treatment (P<0.05).

In the present study, the floor cooling reduced ($P < 0.01$) the weaning-to-oestrus interval of the sows. Based on this result we can infer that the reduction in body weight mobilization associated to a higher daily feed intake and the increase of the sows thermal comfort and welfare, contributed for this reduction in the weaning-to-oestrus interval. The extended weaning-to-oestrus interval after greater lactation weight loss in primiparous sows has been well reported in previous studies (Prunier et al., 1993 and Yang et al., 2000), although generally at lower levels of lactation feed intake than achieved here. The nutritional status of the lactating primiparous sow can induce acute and chronic changes in the reproductive axis (Foxcroft et al., 1997). The reduced feed intake associated to higher BW losses can decrease ovulation rates (Zak et al., 1997) and influence the quality of growing follicles (Britt et al., 1999). Consistent with our findings, Thacker and Bilkei (2005) observed that the weaning-to-oestrus interval was reduced when weight losses during lactation where < 5%.

Conclusions

The dietary AA content had no effect on the performance and behaviour of the sows and their litters. The cooling of the floor under the sows increased daily feed intake, and as a consequence, increased lysine intake. This fact leads to a lower body weight loss and a lower weaning-to-oestrus interval. The floor cooling also improved the nursing behaviour of the sows, leading to a higher milk production and, consequently, higher weight gains for piglets and litter during the lactation period. The detrimental effect of exposure to high ambient temperature and humidity fluctuations on voluntary feed intake and lactation performance of lactating primiparous sows can be reduced by using the floor cooling system.

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Effects of dietary protein level and amino acids supplementation on performance of multiparous lactating sows in a tropical humid climate

Abstract - Eighty six 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 performance under humid tropical climatic conditions. This experiment was conducted in Guadeloupe (West French Indies, lat 16°N, long 61°W) between February 2007 and January 2008. Two seasons were distinguished a posteriori from climatic measurements parameters continuously recorded in the farrowing room. The average minimum and maximum ambient temperatures and average daily relative humidity for the warm season were 20.5 and 28.2°C, and 93.8%, respectively. The corresponding values for the hot season were 22.7 and 29.4°C, and 93.7%. The dietary experimental treatments were: a normal protein diet (NP; 17.3%), a low protein diet (LP; 14.1%) and a NP diet (NP+; 17.6%) supplemented with essential AA. The NP and LP diets supplied the same levels of standardized digestible lysine (i.e., 0.80 g/MJ of NE) and the NP+ diet supplied 0.95 g/MJ of NE. No interaction between season and diet composition was found. Average daily feed intake (ADFI) was lower ($P < 0.05$) in the hot season (i.e., 3.69 vs. 4.72 kg/d). The ADFI tended to be higher with the LP and NP+ diets (i.e., +10%, $P = 0.08$). Litter BW gain and mean BW of piglets at weaning were higher ($P < 0.05$) during the warm season than during the hot season (2.3 vs. 1.8 kg/d and 7.5 vs. 7.1 kg, respectively). Milk production and composition was not affected by dietary treatments but was affected by season (8.1 vs. 6.8 kg/d, respectively for warm and hot seasons; $P < 0.01$). Daily consumption of solid creep feed during the 4th wk of lactation (on average 988 g/ litter) was not affected by season nor by dietary content. The lactation BW loss was lower for the sows submitted to NP+ diet when compared with the NP and LP diets (21.8 vs. 27.0 and 25.4, respectively). The sows fed LP and NP+ diets showed lower backfat thickness losses (3.3 and 3.8 mm, respectively). The weaning to oestrus interval in warm and hot seasons averaged 3.7 and 4.5 d, respectively ($P < 0.05$). In conclusion, the hot season in humid tropical climates, which combines high levels of temperature and humidity, has an important negative impact on performance of lactating sows. Diets with low CP content or supplemented with essential AA can attenuate the effects of hot and humid season by increasing ADFI and reducing BW loss in lactating sows.

Key Words: Feed intake, Protein, Lysine, Lactation, Sows, Tropical Climate

Efeitos do nivel de protiena da dieta e da suplementação de aminacidos sobre o desempenho de porcas multiparas lactantes em clima tropical umido

Resumo – 86 porcas, Large White, de diferentes ordens de parto foram usadas para determinar os efeitos de dietas com redução do conteudo de PB ou suplmentadas com AA industriais sobre o desempenho das mesmas durante um periodo de 28 dias de lactação sob condições de clima tropical umido. Este experimento foi conduzido em Guadeloupe (territorio da França no Mar do Caribe, lat 16°N, long 61°W) entre fevereiro 2007 e janeiro 2008. Duas estações foram determinadas a posteriori dos dados climaticos obtidos recordados dentro das maternidades. As temperturas médias, minima e maxima e a umidade relativa diaria para a estação morna foram 20,5 e 28,2°C, respectivamente e 93,8%. Os valores correspondentes para a estação quente foram 22,7 e 29,4°C, e 93,7%. Os tratamentos foram assim constituidos: nivel de proteina normal (PN; 17,3%), baixa proteina (BP; 14,1%) e a dieta PN suplementada com AA essenciais (PN+; 17,6%). As dietas PN e BP supriram os mesmo niveis de lisina digestivel (0,80 g/MJ de EL) e a dieta PN+ supriu 0,95 g/MJ de EL. Nenhuma interação entre estação e dieta foi observado. O consumo de ração diario (CRD) foi menor (P<0,05) na estação quente (3,69 vs. 4,72 kg/d) e tendeu a ser maior para as dietas BP e PN+ (+10%, P=0,08). O ganho de peso da leitegada e a media de peso dos leitões foram maiores (P<0,05) durante a estação morna em relação à estação quente (2,3 vs. 1,8 kg/d e 7,5 vs. 7,1 kg, respectivamente). A produção e a composição do leite não foram afetados pela composiçao da dieta, mas foram afetados pela estaçao (8,1 vs. 6,8 kg/d, respectivamente para estação morna e quente; P<0,01). O consumo de ração diario dos leitões durante a quarta semana de lactação (em média 988 g/leitegada) não foi afetado pela estação ou pela dieta. A perda de massa corporal foi menor para as porcas submetidas à dieta PN+ quando comparado com as dietas PN e BP (21,8 vs. 27,0 e 25,4, repectivamente). As porcas alimentadas com BP e PN+ mostraram menores perdas de espessura de toucinho (3,3 e 3,8 mm, respectivamente). O intervalo desmame-estro nas estações morna e quente foram em média de 3,7 e 4,5 dias, respectivamente (P<0,05). Em conclusão, a estação quente em climas tropicais e umidos, que combina alta temperatura e umidade, tem um importante impacto negativo sobre o desempenho de porcas lactantes. Dietas com baixa PB ou suplementadas com AA industriais podem atenuar os efeitos da estação quente e umida através do aumento do CRD e reduçao na perda de massa corporal das porcas lactantes.

Palavras chaves: consumo de ração; proteina; lisina; lactação; porcas; clima tropical

Introduction

According to FAO predictions, pig production in tropical and subtropical countries will rapidly increase as a result of increasing human population. Although many factors are obviously involved, the combination of high temperatures and high relative humidity resulting in heat stress remains one of the major problems that affect the production efficiency of pigs in these regions. In fact, while heat stress is only an occasional problem during the summer period in temperate regions, it is a continuous problem in tropical and subtropical areas. According to their high nutrient requirements, lactating sows are particularly sensitive to high ambient temperatures. When ambient temperature increases above the evaporative critical temperature (i.e. 22°C; Quiniou and Noblet, 1999), the sow reduces its voluntary feed intake (VFI) in order to reduce heat production due to the thermal effect of feed (TEF). This reduced VFI has negative consequences on body reserves mobilization, milk production and sows' future reproductive and productive career (Dourmad et al., 1998). Alternatives to reduce heat stress have been developed to maintain sows performance under high temperature conditions by increasing heat loss using drip cooling system (McGlone et al., 1988), chilled drinking water (Jeon et al., 2006) or floor cooling system (Silva et al., 2006). An alternative approach consists in attenuating the change of feed intake in hot conditions using low increment diets and/or increasing dietary energy content (Renaudeau et al., 2001; Le Bellego et al., 2002). However, most of the studies published on these issues were obtained in climatic rooms using constant levels of temperature at a low relative humidity (60-70%). From that point of view, very little is published on the effects of diet manipulation on performance of sows raised in tropical humid climate. Under these areas, sows are usually exposed to outside climatic conditions with high diurnal temperature and relative humidity.

The objective of this study was to evaluate how diets with reduced TEF or supplemented with essential AA can attenuate the effects of tropical climate on performance of sows and their litters during lactation.

Materials and Methods

Experimental Design

Ten successive replicates of eight to ten mixed-parity Large White sows (89 in total) were used in a trial conducted at the INRA experimental facilities in Guadeloupe, French West Indies (Latitude 16°N, Longitude 61°W) considered as a tropical humid climate area (Berbigier, 1988). This study covered the period between February 2007 and January 2008. Two seasons were distinguished *a posteriori* from climatic measurements parameters continuously recorded in the farrowing room.

Within each replicate, sows were distributed in a completely randomized experimental design between three dietary treatments according to backfat thickness, parity order and BW after farrowing. The dietary experimental treatments were: a normal protein diet (NP), a low protein diet (LP) and a NP diet supplemented with an amino acid (AA) complement (NP+). The experimental diets (Table 10) 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 levels of standardized digestible lysine (i.e., 0.80 g/MJ of NE) and the NP+ diet supplied 0.95 g/MJ of NE. For the calculation of the AA complement composition in the NP+ treatment, an average daily feed intake of 5 kg/d was considered, and the lysine content level was increased until the first essential AA became limiting (i.e., phenylalanine + tyrosine), after available synthetic AAs were added to maintain a constant ratio between the essential AAs and lysine. Practically, every morning, 53 g of the calculated AA complement was incorporated manually in the NP diet before distribution to the sows. The levels of digestible essential AAs relative to digestible lysine were similar for the three diets. The ratio between digestible essential amino acids and digestible lysine in the experimental diets were calculated to ensure that they were not below that of the ideal protein recommended for this animal category (Renaudeau et al., 2003). Chemical composition and nutritional value of diets are presented in Table 11. Diets were offered as pellets. Feeds were prepared for one or two successive replicates and stored in a temperature-controlled room (24°C, 50-60% RH).

Animal Management

During the gestation period, sows were housed in open-fronted gestating pens in groups of five sows each and restrictively fed a conventional diet based on maize, wheat middlings and soybean meal (13 MJ DE/kg, 140 g CP/kg). Feed allowance during the first 30 d after mating was calculated to standardize body condition at farrowing, according to

Table 7 - Composition of the lactation diets, as fed

Item	NP	LP	AAs complement[1]
Ingredients, %			
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 HCL	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[2]	1.1	1.1	-

[1] AAs complement calculation: lysine content was increased in the NP diet until the other essential AAs (phen + tyr, his, arg, leuc) become limiting following the NRC recommendations for AA/lysine: 111, 39, 55, 110, for phen + tyr, hist, arg, leuc, respectively. For the calculations of the AA complement an estimated ADFI of 5000 g/d was used. 53 g of the AA complement was offered daily to each NP+ sow.
[2] Minerals and vitamins mixture supplied (g/kg of diet): 10 of Cu (as $CuSo_4$); 80 of Fe (as $FeSO_4.7H_2O$); 40 of Mn (as MnO); 100 of Zn (as ZnO); 0.6 of I (as $Ca(IO_3)2$); 0.10 of CO (as $CoSO_4.7H_2O$); 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 thiamin; 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.

the model proposed by Dourmad et al. (1997). The feeding level was fixed at 2.5 kg/d from the 30th to the 114th of gestation. Ten days before parturition, sows were moved to open-fronted farrowing pens (2.1 x 2.2 m) on a slatted metal floor.

Variations in ambient temperature, relative humidity, and photoperiod closely followed outdoor conditions. On d 1 postpartum, sows received 1 kg of the standard gestation diet and the allowance increased by 1 kg each day until d 4 of lactation to avoid over-consumption at the beginning of lactation and agalaxia problems. The proportion of gestation diet decreased progressively over the 4-d postpartum (1.00, 0.75, 0.50 and 0.25 on d 1, 2, 3 and 4, respectively), and sows were fed only the lactation diet on d 5. From d 6 to d 26 postpartum, sows were fed *ad libitum*. The day prior to weaning (i.e., d 27), sows were allowed 3 kg of feed (i.e., at least 1.5 kg lower than their usual feed intake) to standardize consumption for all sows for determination of sow weight at weaning. After birth, piglets were handled for tooth cutting, umbilical cord treatment and labelling. On d 3, they received an intramuscular injection of 200 mg of iron dextran. If necessary, cross-fostering was realized within the first 48 h after birth to standardize litter size at 10 or 11 piglets.. On d 14, male piglets were castrated. After 21 days of lactation, piglets were

Table 8 - Analyzed chemical composition of the lactation diets, % DM basis

Analyzed composition	NP	LP	NP+
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,[1] %	4.52	5.37	4.83
Calculated Nutritional Value[2]			
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] [Percentage of tryptophan/(% isoleucine + % leucine + % valine + % phenylalanine + % tyrosine)] x 100.
[2] NE values was estimated form the chemical composition 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 INRA Tables (Sauvant et al., 2003).

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 days 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 oestrus. From 28 d after mating, all sows were checked for pregnancy diagnosis using an ultrasonography (Agroscan, E.C.M., Angoulême, France).

Measurements and Chemical Analyses

Sows were weighed after farrowing and at weaning. Backfat thickness measurements were taken ultrasonically (Agroscan, E.C.M., Angoulême, France) at 65 mm from the midline at the point beside the shoulder and at the last rib on each flank 2 d before farrowing and at weaning. The total number of piglets born, alive, stillborn, and dead during lactation was recorded for each litter. Piglets were individually weighed at birth, at d 14 and 21 of lactation and at weaning. Every morning, feed refusals were collected, and fresh feed was immediately distributed, once per day between 0700 and 0900. Feed consumption was determined as the difference between feed allowance and the refusals collected on the next morning. Every day, one sample of offered feed and feed refusals was collected for DM content measurement, and successive samples were pooled and stored at 4°C for further analyses. Before sampling the NP+ refusal, these were homogenised manually in order to guarantee that during the sampling, residues of the AAs complement were also incorporated to the sample. Rectal temperatures and respiratory rhythm of each sow were measured on Monday and Thursday at 0700 and 1200 from Monday before farrowing to the Monday after weaning. Ambient temperature and relative humidity were continuously recorded (one measurement every 30 s) in the farrowing room, using a probe (Campbell Scientific Ltd., Shepshed, U.K.) placed at 1 m above the floor.

At d 14, piglets were separated from the sows after suckling, and 50 min later (i.e., equivalent to average suckling interval; Renaudeau and Noblet, 2001), the sow was injected with 10 IU of oxytocin (Intervet, Angers, France) in an ear vein and all functional mammary glands were hand milked. Samples (approximately 100 mL) were immediately stored at -20°C for further analyses.

Feed (two samples per diet and per replicate) and milk (three samples per sow) samples were analyzed for DM, ash, fat content (AOAC, 1990) and CP (N x 6.25) according to Dumas method (AOAC, 1990). Feed was analyzed for crude fiber and for cell wall components (NDF, ADF, and ADL) according to Van Soest and Wine (1967). Lactose content in milk was determined using an enzymatic method (Boehringer Mannheim, reference No. 176303). Feed and milk AA contents were analyzed by Ajinomoto Eurolysine (Amiens, France) using an ion-exchange chromatography, except for tryptophan, which was analyzed using HPLC and fluorimetric detection (Waters 600E, St. Quentin en Yvelines, France).

Calculations and Statistical Analyses

Daily maximum, minimum, mean, and variance of daily ambient temperatures and relative humidities were averaged for each replicate. These data were used to split the total experiment period between two seasons through a principal component analysis (PRINCOMP procedure, SAS Inst., Inc, Cary, NC). The effects of season, diet composition, replicate, parity number, and their interactions on sows and litter performance were tested according to a general linear procedure analysis of variance (GLM procedure of SAS). The average daily rectal temperature (RT) and respiratory rate (RR) (defined as the mean of RT and RR measurements at 0700 and at 1200) measurements were pooled per sow over the lactation period. These data were analyzed using the same previous model. The effect of lactation stage on daily feed intake was tested with a mixed linear model (Mixed procedure of SAS) for repeated measurements with diet composition, season and replicate as main effects. The least square means procedure (PDIFF option) was used to compare means when a significant F-value was obtained. The number of sows returning into oestrus before and after 5 d post-weaning were compared using a $\chi 2$ test (Freq procedure of SAS).

Results

Climatic Measurements

The warm season was determined to be between February and April 2007 and between November 2007 and January 2008, whereas the hot season corresponded to May to October 2007 period. The average minimum and maximum ambient temperatures and average relative humidity for the warm season were 20.5 and 28.2°C, and 93.8%, respectively. The corresponding values for the hot season were 22.7 and 29.4°C, and 93.7%, respectively. The mean temperature values for warm and hot season were 23.7 and 26.1, respectively (Table 12).

Sow Performance

Because of low litter size (< 6 piglets), three sows were removed from the study. No interaction (P > 0.10) between season and diet composition was found for all criteria studied. According to the design, parity number averaged 3.2 and was not affected by season or by diet composition. Lactation length was higher in the hot season than in the warm season (29.2 vs. 28.1; Table 13), but no difference in lactation length was observed between dietary treatments (28.6 d on average).

As presented in Table 13, ADFI was affected (P < 0.001) by parity and season with a lower feed consumption in the hot season during the whole lactation period and during the *ad libitum* period (4.72 vs. 3.69 kg/d; and 5.36 vs. 4.13 kg/d, respectively).

After farrowing, sows were restrictively fed for 5 d according to the same feeding plan and the increase of ADFI was similar for both seasons until d 4 (Figure 2). After d 4, the ADFI tended to be higher for LP and NP+ diets when compared to NP diet during the

Table 9 - Main characteristics of climatic parameters[1]

	Season	
Items	Warm	Hot
Temperature (°C)		
Minimal	20.7	23.3
Maximal	28.0	29.4
Mean	23.7	26.1
Relative humidity (%)		
Minimal	82.3	87.0
Maximal	98.4	97.7
Mean	93.5	93.7

[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.

whole lactation period and during the ad libitum period (i.e., 4.35 vs. 3.89 and 4.92 vs. 4.39 kg/d, respectively; P = 0.10). The ADFI of sows fed LP and NP+ diets increased with the advancement of lactation after d 4 in relation to NP sows (Figure 3).

Milk production between d 1 and d 21 was higher (P < 0.01) in the warm season than in the hot season (8.1 vs. 6.8 kg/d, respectively). Milk lipid content was higher in the hot season than in the warm season (38.7 vs. 33.1%; P < 0.05) and protein content tended to be higher in the warm season (27.1 vs. 25.1%; P = 0.05). Milk production and composition were not affected by diet composition (Table 15).

The lactation BW and backfat thickness losses were not affected (P > 0. 10) by the season (Table 13). The lactation BW loss was lower for the NP+ than the NP or LP sows (21.8 vs. 26.2 kg; P > 0.10). LP and NP+ sows showed a numerically lower BT loss than NP sows (3.5 vs. 5.4 mm; P = 0.10). Body protein, lipid and energy contents losses were not affected by the treatments (P > 0.10); however, NP diet sows had numerically higher lipid and energy losses (+3.1 kg and 130 MJ, respectively) when compared to sows fed the LP and NP+ diets. Rectal temperature was higher (P < 0.001) in the hot season than in the warm season (38.8 vs. 38.4°C). Sows submitted to NP and NP+ diets had a higher RT when compared with LP diet (38.6 vs. 38.5°C; P > 0.10; Table 13).

The reproductive performance was measured for a total of 86 sows; but five sows (3, 1 and 1 sows fed NP, LP and NP+, respectively) did not show oestrus until d 15 after weaning and the weaning-to-oestrus interval (WEI) was calculated on a total of 81 sows. The WEI averaged 3.7 and 4.5 d (P < 0.05) for the warm and hot seasons, respectively

(Table 16). The percentage of sows with a delayed oestrus was higher in the hot than in the warm season (6.2 vs. 0 %; $P < 0.05$).

Litter Performance

Litter size and the average piglet BW at birth were not affected ($P > 0.05$) by season. Whatever the treatment, the litter BW gain numerically increased between wk 1 and wk 3 and between wk 3 and wk 4. Litter BW gain between birth and weaning and mean BW of piglets at weaning were higher ($P < 0.05$) during the warm season than during the hot season (2.3 vs. 1.8 kg/d and 7.5 vs. 7.1 kg). Litter BW gain during the lactation period was not affected by dietary treatment ($P > 0.10$). Daily consumption of solid creep feed (Table 13) during the 4^{th} wk of lactation was neither affected by diet composition nor by season ($P > 0.10$).

Discussion

Effect of Season on Sow and Litter Performance

The effect of high ambient temperatures on the performance of lactating sows and their litters is well known in the literature (Black et al., 1993; Renaudeau et al., 2003). In tropical humid conditions, the average temperatures observed during the warm and the hot seasons are above the upper limit thermoneutral zone of the sows (i.e. 22°C; Quiniou and Noblet, 1999). Under our tropical humid conditions, the mean temperatures observed during the warm and hot season (23.7 and 26.1°C, respectively) exceeded 22°C. In addition, this 22°C value was obtained at low RH and it probably overestimates the upper limit of the zone of thermo neutrality when the RH is close to 100%. Therefore, lactating sows suffered from heat stress most of the time in our experimental conditions. This effect was accentuated during the hot season in connection with the higher average daily temperature (i.e., +2.5°C). This is consistent with the increase of rectal temperature (i.e., + 0.4°C), increase of the respiratory rate (i.e., + 9 breaths/min) and the sharp reduction of ADFI during the hot season. However, the average rectal temperature recorded during the warm and the hot seasons was lower than values measured by Lorschy et al. (1991) and Quiniou and Noblet (1999) at 25 and 27°C (i.e., 38.2 vs. 39.3°C and 38.6 vs. 39.5°C, respectively). Moreover, the increase in respiratory rate observed from warm to hot season

(+4.0 breaths/min/°C) is lower than values reported in other studies using high temperatures (+7.1, +8.9 and 8.0 breaths/min/°C, according to Lorschy et al., 1991, and Quiniou and Noblet, 1999, Renaudeau et al., 2001, respectively). The low increase observed in the respiratory rate between seasons in our study can be related to the fact that sows in the warm season were already heat stressed, implicating a small increase of RR when ambient temperature was elevated in the hot season. Taking into account the low cutaneous evaporative capacities in pigs, an important rise in respiratory rate is required in pigs for an effective increase of evaporative heat losses. All these processes correspond to a short-term adaptation to hot climatic conditions via increased heat dissipation.

The negative effect of high temperatures on feed intake has been extensively described in literature (Christon et al. 1999; Johnston et al., 1999; Quiniou and Noblet, 1999; Renaudeau et al., 2003: Gourdine et al., 2006). Quiniou and Noblet (1999) showed that the effect of temperature on ADFI is accentuated as the ambient temperature increases. In their study, they indicated that each degree increase in ambient temperature between 25 and 27°C at a relative humidity fluctuating between 50 and 60% resulted in a reduction of feed intake equivalent to 214 g/d. In our study, over a similar temperature range between the two seasons and at approximately 94% relative humidity, the corresponding value was more than twice higher (492 $g.d^{-1}.°C^{-1}$). Renaudeau et al. (2003) evaluating the effects of dietary fibre content in the same tropical conditions as ours, i.e. a similar range of ambient temperatures and relative humidity, observed a reduction of 584 $g.^{-1}.C^{-1}$ in ADFI between both seasons. These results suggest that the reduction in feed intake of lactating sows kept in tropical climates is related to the combined effects of high temperatures and high humidity. This emphasizes that the high humidity accentuates the effect of high temperatures by limiting the capacity of evaporative heat loss from the lungs through increased respiratory rate (Renaudeau, 2005).

In the warm season, piglet growth rate over the first 3 wk of lactation (i.e., 194 g/d) was lower than results reported in temperate conditions (Auldist and King, 1995: 265 g/d; Hulten et al., 2002: 290 g/d; Quiniou et al., 2005: 253 g/d). As observed for ADFI, this suggests that the sows in our study were heat stressed and their milk production was depressed, even in the warm season. According to Quiniou and Noblet (1999) and Gourdine et al. (2006), milk yield is reduced at elevated temperatures. In the current study, the effect of season on milk production and on litter BW gain was significant, with lower values during the hot season. Moreover, when milk production was expressed per piglet, the amount of milk available for each piglet decreased in the hot season, which indicates that the negative effect of heat stress on sow milk production was emphasized during the hot season. Independently of the season, piglet BW gain between d 21 and weaning was greater than piglet gain from wk 1 to wk 3 of lactation, in connection with creep feed allowance during this period. In the present study, piglets consumed similar amounts of creep feed during the warm and hot seasons (14 vs. 13 g/d/piglet, respectively). Different from our findings, Renaudeau and Noblet (2001) found a higher creep feed intake in piglets from sows maintained under heat stress conditions (i.e., 23 vs. 38 g/d/piglet, respectively for 20 and 29°C; $P < 0.01$). According to these authors, piglets compensated for the lower milk production by increasing their creep feed consumption with a subsequent attenuated effect of heat stress on performance of the litter. The difference observed between our findings and the latter authors can be related to the fact that the range of temperature in our experiment was too low to impact on creep feed intake (2.4°C vs. 9.0°C, respectively for our study and Renaudeau and Noblet, 2001).

In agreement with Renaudeau and Noblet (2001), our results show an increased lipid content of milk in sows exposed to hot climatic conditions. Similar results were obtained at thermoneutrality when dietary energy supply was reduced and mobilization of body fat reserves was accentuated (Noblet and Etienne, 1986). The combination of both groups of results would indicate that moderate changes in milk composition when sows are exposed to high ambient temperature are related to the more intense mobilization of body fat reserves.

The sows BW, protein, lipid, energy and backfat thickness losses were not affected by the season. Different from our results, most literature studies on this topic show that BW loss increases in heat stressed sows in connection with a reduced ADFI (Christon et al., 1999; Johnston et al., 1999; Quiniou and Noblet, 1999; Renaudeau et al., 2003) and a smaller reduction of performance. A possible explanation for our findings is that the sows were more efficient to produce milk from feed intake energy than from body content energy in the hot season, resulting in no effects on chemical composition of BW loss. Our study showed a significant effect of season on weaning-to-oestrus interval, where the sows showed a higher WEI in the hot season than in the warm season (i.e., 4.5 vs. 3.7 d). Shaw and Foxcroft (1985), Barb et al. (1993), Koketsu et al. (1997) and Van den Brand et al. (2000) also observed a negative effect of high temperature on the return to oestrus of sows after weaning. According to these authors, the delay in the return to oestrus after weaning was related to a lower secretion of LH in sows maintained in a hot environment.

Table 10 - Effects of season and diet composition on performance of lactating sows over a 28-d lactation (least square means)

Variable	Diet			Season		RSD[1]	Statistical Analysis[2]
	NP	LP	NP+	Warm	Hot		
N° of lactations	30	30	26	33	53		
Average parity	3.3	3.2	3.3	3.3	3.2	1.2	P***
Lactation length, d	28.4	29.3	28.2	28.1	29.2	2.7	
ADFI, as fed							
From d 1 to weaning, kg/d	3.89	4.36	4.35	4.72	3.69	0.65	D†, S***, G*, P***
From d 6 to d 26, kg/d	4.39	4.93	4.91	5.36	4.13	0.81	D†, S***, G*, P***
From d 6 to d 26, g/d/kg $BW^{0.75}$ [3]	55.2	55.8	56.7	55.7	56.1	5.6	P***
Body weight (BW), kg							
After farrowing	224.6	226.9	229.6	226.9	227.2	29.1	P***
At weaning	197.6	201.5	207.8	203.5	201.0	30.9	P***
Loss during lactation	27.0	25.4	21.8	25.8	23.6	12.7	
Backfat thickness, mm							
After farrowing	17.7	16.9	18.8	18.4	17.3	3.8	
At weaning	12.3	13.6	14.9	14.7	12.5	2.8	D†, S*, G†, P*
Loss during lactation	5.4	3.3	3.8	3.6	4.7	2.5	D†, P†
Chemical composition of BW loss[4]							
Proteins, kg	3.2	3.6	2.8	3.6	2.8	2.0	
Lipids, kg	13.4	10.3	10.2	10.8	11.8	5.2	
Energy, MJ	635	517	493	538	558	245	
Rectal temperature,[7] °C	38.6	38.5	38.6	38.4	38.8	0.2	
Respiratory rate,[7] breaths/min	61	59	58	55	64	9	

[1] RSD: Residual standard deviation.
[2] From an Generalized Linear Model 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). Statistical significance: ****P < 0.001*, ***P < 0.01*, **P < 0.05*, †*P ≥ 0.05*.
[3] Metabolic BW = (BW at $weaning^{1.75}$ – BW at $farrowing^{1.75}$)/[1.75 x (BW at weaning – BW at farrowing)].
[4] Estimated form equations published by Dourmad et al. (1998) Protein (kg) = 2.28 (2.22) + 0.178 (0.017) x empty BW – 0.333 (0.067) x P2 (RSD = 1.9), Lipids (kg) = -26.4 (4.5) + 0.221 (0.030) x empty BW + 1.331 (0.140) x P2 (RSD = 6.1), Energy (MJ) = -1.075 (159) + 13.67 (1.12) x empty BW + 45.98 (4.93) x P2 (RSD = 208). Empty BW (kg) = a x $BW^{1.013}$ (kg), with a = 0.912 at farrowing and a = 0.905 at weaning. P2 = P2 backfat thickness (mm).
[7] Measured at 0700 and 1200 every Monday and Thursday during the lactation.

In the present study, LP sows tended to increase ADFI (+ 540 kg/d) when compared to the NP diet sows. Our results show that the increase of ADFI with LP diet was quite similar in multiparous and in primiparous sows (+11%, respectively). Renaudeau et al. (2001) evaluating the effect of protein reduction (14.2 vs. 17.6%) also reported a numerical increase of ADFI at 29°C for sows fed LP diet (+639 kg/d). Lynch (1989) also observed an increased feed consumption (+700 g/d) in multiparous lactating sows fed a low CP diet (14 vs. 20%) at 28°C. In contrast, Quiniou and Noblet (1999) did not report any effect of diet on performance of lactating sows kept at 29°C when dietary protein content was reduced from 17 to 14%. In that study, the authors attributed the lack of interaction between temperature and diet to the low number of observations and (or) the lower supplies of sulphur amino acids and tryptophan expressed as a percentage of lysine in the 14% CP diet.

According to the net energy system, heat increment due to metabolic utilization of digestible crude protein (CP) is significantly higher than for starch or ether extract (42 vs. 18 and 10% of the ME content; Noblet et al., 1994). It can then be hypothesized that the LP diet reduced the thermal effect of feed and attenuated the reduction of feed intake associated to heat stress.

In addition, the reduction of dietary protein content with a supplementation of synthetic AA leads to increase the ratio between tryptophan and branched chain amino acids (LNAA: Leu, ILeu, Val, Phe, and Tyr) (i.e., 4.52 vs 5.37% in NP and LP diet, respectively , respectively). According to Tackman et al. (1990), tryptophan and LNAA share the same neutral carrier system to cross the blood-brain barrier and they compete for uptake by the brain. Serotonin and its precursor, tryptophan, are known to be involved in the control of feed intake; an increased ratio of tryptophan:LNAA is reported to increase linearly the appetite (Henry et al., 1992; Henry and Sève, 1993). Trottier and Easter (1995) reported that a reduction in the tryptophan:LNAA ratio through dietary addition of LNAA decreased feed intake of primiparous lactating sows. Thus, it could be suggested that the increased ADFI in LP treatment would be also related to a reduced TRP:LNAA ratio.

Litter BW gain, milk production and composition were not influenced by dietary CP content. Similarly, Johnston et al. (1999) and Renaudeau et al. (2001) in lactating sows kept at 29°C, showed no change in litter BW gain when dietary CP level was decreased (from 16.7 to 13.3%; and from 17.6 to 14.2%, respectively).

Table 11 - Effect of season and diet composition on performance of litters over a 28-d lactation (least square means)

Variable	Diet			Season		RSD[1]	Statistical Analysis[2]
	NP	LP	NP+	Warm	Hot		
N° of lactations	30	30	26	33	53		
Parity	3.3	3.2	3.3	3.3	3.2	1.2	P***
Lactation length, d	28.4	29.8	28.5	28.1	29.2	2.7	
Litter size							
At d 1[3]	12.2	12.4	11.4	12.2	11.8	1.9	G**
At weaning	10.1	10.1	10.7	10.7	9.8	1.3	S*, G**
Piglet BW, kg							
At d 1	1.4	1.4	1.4	1.4	1.4	0.2	
At d 14	4.2	4.2	4.2	4.3	4.2	0.7	G*
At d 21	5.7	5.7	5.6	5.8	5.5	0.7	
At weaning	7.5	7.4	7.1	7.5	7.1	0.8	S†
Litter BW gain, kg/d							
Wk 1 to 3	2.1	2.0	2.0	2.2	1.8	0.4	S**, G*
Wk 4	2.5	2.4	2.2	2.6	2.1	0.6	S*
Wk 1 to 4	2.2	2.1	2.1	2.3	1.8	0.4	S***
Total creep-feed consumption, piglet/4th wk	99	108	82	102	91	131	P†
Total creep-feed consumption, litter/4th wk	981	1100	883	1064	912	1335	P†
Sow milk production[4] (kg/d)	7.6	7.3	7.5	8.1	6.8	1.4	S**, G*

[1] RSD: Residual standard deviation

[2] From an Generalized Linear Model 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). Statistical significance: ***P < 0.001, **P < 0.01, *P < 0.05, †P ≥ 0.05.

[3] After cross fostering.

[4] 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 dry matter using the equation from Noblet and Etienne (1989).

Table 12 - Effect of season and diet composition on milk composition[1] (least square values)

Item	Diet			Season		RSD[2]	Statistical Analysis[3]
	NP	LP	NP+	Warm	Hot		
N° of lactations	22	21	21	13	51		
Milk composition (as is)							
DM, %	19.7	20.3	19.4	19.8	19.8	1.4	G***
Proteins (N x 6.38), %	26.7	25.9	26.3	27.1	25.1	1.6	S†, G**
Ash, %	4.3	4.2	4.1	4.3	4.1	0.3	G*
Lipids, %	34.1	38.4	35.2	33.1	38.7	5.5	S*, G**

[1]Milk collected at d 14.
[2]RSD: Residual standard deviation
[3]From an Generalized Linear Model 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). Statistical significance: ****P < 0.001*, ***P < 0.01*, **P < 0.05*, †*P ≥ 0.05*.

Table 13 - Effect of season and diet composition on the weaning-to-oestrus interval (least square values)

Item	Diet			Season		RSD[1]	Statistical Analysis[2]
	NP	LP	NP+	Warm	Hot		
N° of lactations	27	29	25	32	49		
Weaning-to-oestrus interval (n)							
1 – 3 d	6	6	6	12	6		
3 - 5 d	19	22	17	21	40		
>5 d	2	1	2	20	5		
Weaning-to-oestrus interval (d)	4.2	4.2	4.0	3.7	4.5	1.0	S*, G*
	$\chi^2 = 0.74$, $P = 0.94$			$\chi^2 = 9.50$, $P = 0.009$			

[1]. RSD: Residual standard deviation
[2] From an Generalized Linear Model 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). Statistical significance: **P < 0.05*.

Evaluating the effect of dietary CP content on the performance of lactating sows under heat stress, Renaudeau et al. (2001) observed that the LP sows showed a higher daily feed intake and lost less BW in comparison with NP sows. In the present study, the reduction of BW mobilization in sows fed LP diet was very low (-1.6 kg). The estimated chemical composition of BW loss was not affected by the diet composition. On average, each 100 g BW loss contained 14 g of proteins and 47 g of lipids. Evaluating diets comparable to ours, Renaudeau et al. (2001) reported similar values of body nutrient change (12% and 46%, respectively, for protein and lipid content in BW loss) for multiparous sows over a 27 d lactation. In our study, the lack of significant of diet on reproductive performance was mainly related to the fact that dietary treatment did not affect BW reserves mobilization.

Effect of Dietary Amino Acid Content on Sow and Litter Performance

In the present study, sows fed NP+ diet showed, on average a higher ADFI when compared to sows fed NP diet (i.e., +10.6%). Although we did not evaluate the performance of the primiparous sows independently, because of a low number of primiparous sows, the higher feed intake observed for the NP+ sows can be partly attributed to a higher effect on the primiparous sows, which showed a high feed intake when fed with an amino acids complement. In this sense, but different from our results, Tokach et al. (1992) and Paiva et al. (2005), evaluating the effects of lysine levels in lactating primiparous sows, via an addition of synthetic amino acids, did not observe a significant effect of the increase of amino acids content on average daily feed intake. It is well established (Nieto et al, 1995) that at similar rates of energy intake protein accretion is higher as dietary protein concentration is increased to an optimum. With differences in protein quality rather than quantity the situation is less clear. In growing pigs, Van Milgen et al. (2001) found that the rate of heat production was not significantly changed, whereas the rate of protein accretion increased. According to Nieto et al. (1995), the supplementation with extra protein increased N retention but increased heat production. These changes in protein quality or quantity involved different metabolic responses. These authors also found that increases in the rate of protein accretion resulting from lysine supplementation were brought about primarily by a reduction in body protein breakdown. Therefore, it is assumed that the AA supplementation for the sows fed the NP+ diet

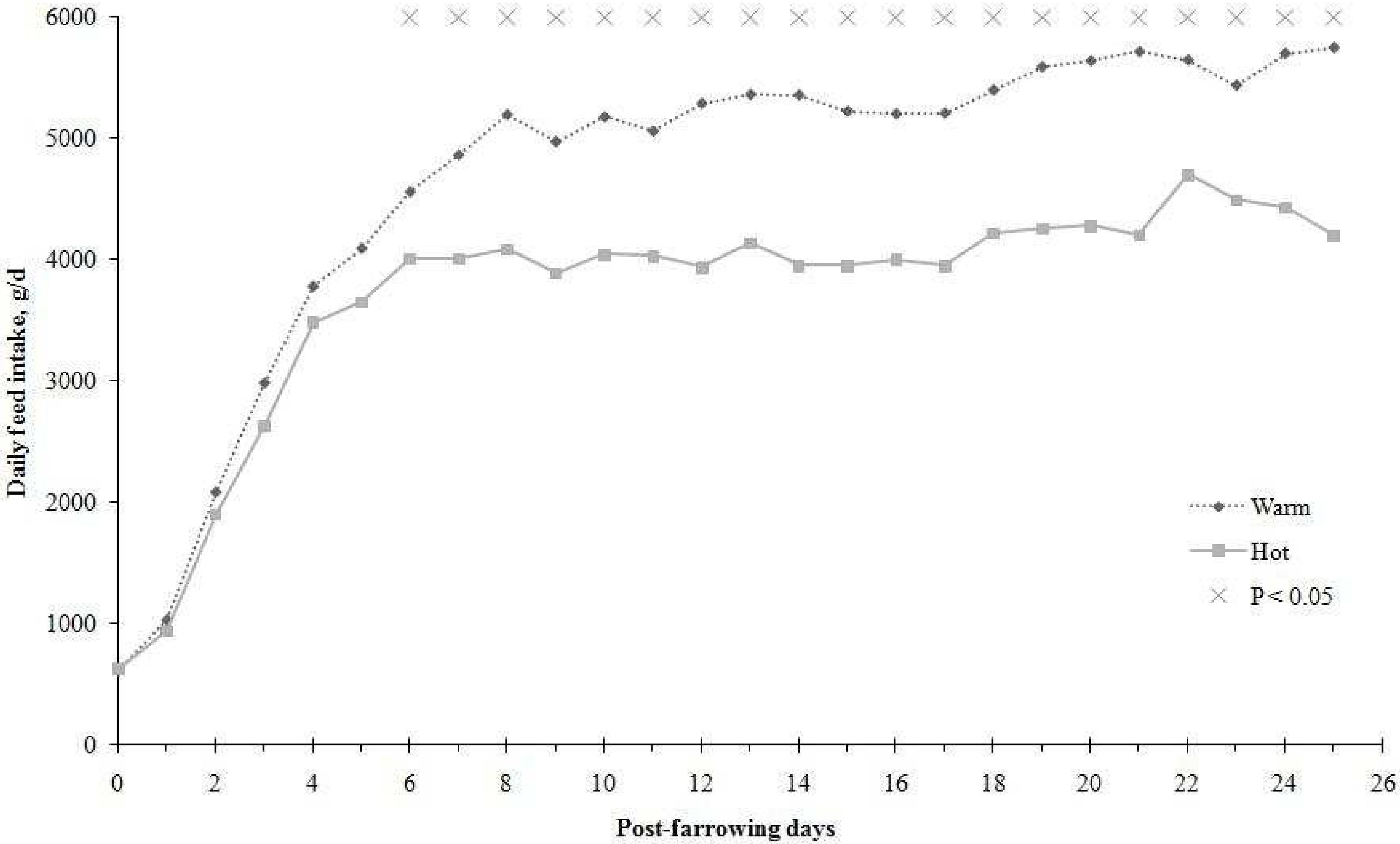

Figure 1 - Effect of season on daily feed intake during the lactation period. Feed intake was not different from d 1 to 5 ($P > 0.05$), whereas it differed between seasons from d 6 to 25 (×: $P < 0.05$). A total of 33 and 53 sows were used for warm and hot seasons, respectively.

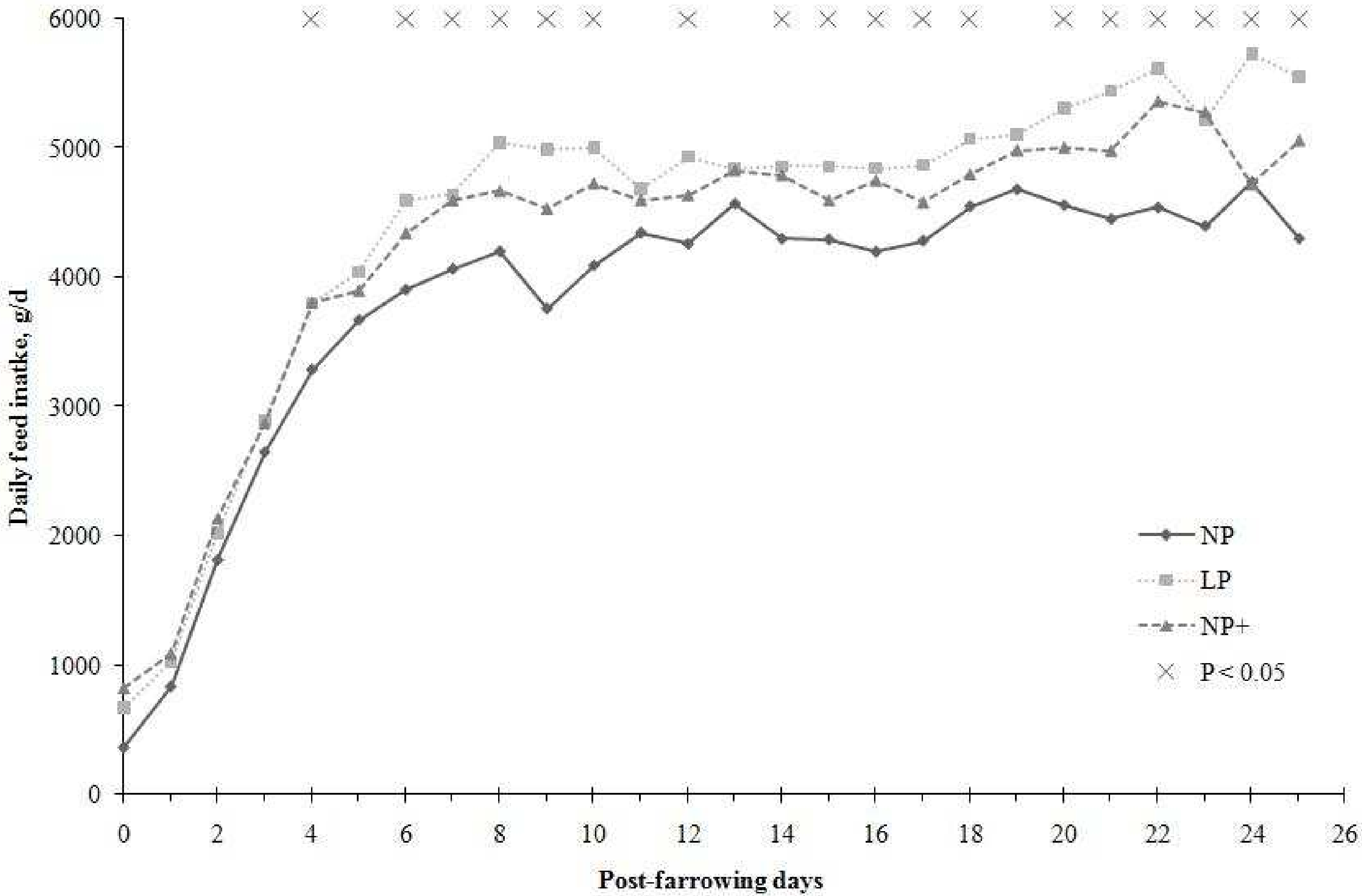

Figure 2 - Effect of diet composition on daily feed intake during the lactation period. Feed intake was not different from d 1 to 3 and on d 5, 11, 13 and 19 ($P > 0.05$), whereas it differed between diets on d 4, from d 6 to 10, d 12, d 14 to 18 and from d 20 to 25 (×: $P < 0.05$). A total of 30, 30 and 26 sows were used for NP, LP and NP+, respectively.

increased protein accretion through a reduced protein degradation with no extra heat production which allowed these sows to increase their feed intake.

Piglet and litter performance and sows milk production were not affected by the dietary AA complement. Similarly, Trottier and Easter (1995), Dourmad et al. (1998), Cota et al. (2003) and Paiva et al. (2005) also did not observe any effect of increasing dietary AA content on piglet and litter performance and on sows' milk yield. Milk composition was not influenced by dietary amino acid content. Similarly, Trottier and Easter (1995) also did not observe any effect of increasing dietary AA content on sow milk composition.

The results of BW, protein, lipid losses, as well as changes in backfat thickness obtained in our study were not affected by the dietary AA supplementation. Nevertheless, when compared between NP+ and NP, a lower BW contents mobilization was found for the sows fed the NP+ diet, but these results are related to the performance of the primiparous sows, which were more affected by AA supplementation. This result can be associated to the effect of the higher lysine content intake observed in these sows (i.e., +11 g/d), which can also be related to the higher ADFI observed for the sows (i.e., +460 g/d). Stahly et al. (1992), Johnston et al. (1993) and Dourmad et al. (1998) also found that the loss of BW was affected by lysine supply, whereas increasing lysine levels in the diets reduced BW loss.

Conclusions

The present study demonstrates that high ambient temperature has an important negative effect on feed intake and more generally on performance of lactating sows and this result is emphasized when the relative humidity is high. Whatever the season, the use of diets with reduced TEF or supplemented with an AA complement in lactation may allow an increase in ADFI and attenuate partially the effects of tropical climate on performance of sows. The addition of AA supplementation in diets for primiparous sows can be a good alternative to attenuate the effects of heat stress on the performance of these animals, but this assumption needs to be more investigated with a higher number of sows. Because of the increase in feed intake observed with the NP+ diet, further studies are required to evaluate the long-term effects of an AA supplementation in diets for lactating sows under heat stress conditions.

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Effects of dietary protein level and amino acids supplementation on the feeding behaviour of multiparous lactating sows in a tropical humid climate

Abstract - Forty seven mixed-parity Large White sows were used to determine the effect of diets with reduced crude protein (CP) content or supplemented with essential amino acid (AA) on 28-d lactation feeding behavior under humid tropical climatic conditions. The trial 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 parameters continuously recorded in the open front farrowing room. Variations in ambient temperature, relative humidity, and photoperiod closely followed outdoor conditions. The average ambient temperature and average daily relative humidity for the warm season was 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 (NP; 17.3%), a low protein diet (LP; 14.1%) and a NP diet supplemented with essential AA (NP+; 17.6%). No interaction between season and diet composition was found for all criteria. Average daily feed intake was lower ($P < 0.01$) during the hot season (i.e., 4.84 vs. 5.81 kg/d). Meal size was reduced during the hot season (542 vs. 757 g/meal; $P < 0.01$). Daily ingestion time (45.5 vs. 55.8 min/d; $P < 0.05$) was lower in the hot season. Meal size was significantly lower during the hot season at night (533 vs. 707 g per meal, respectively; $P < 0.01$). In both the warm and hot seasons, daily feed intake, feed ingestion, and rate of feed intake were significantly lower during the nocturnal than during the diurnal period ($P < 0.05$). The season did not modify the diurnal proportion of feed intake. The sows fed LP diet showed a higher feed intake when compared to NP and NP+ (+11%; $P < 0.05$) which resulted in a non-significant lower BW and backfat thickness losses. The sows fed the LP diet tended to have a higher meal size (+127 g/meal, $P = 0.07$) when compared to the other two diets. The number of meals per day was not significantly affected by season or diet composition. Duration of standing was not affected by diet or season ($P > 0.05$), and it averaged 126 min/d. This study confirms that feeding behavior parameters of the lactating sow is affected by seasonal variations of the tropical climate. Irrespective of season, the reduction of crude protein content increased voluntary feed intake, improved ingestion time and the rate of feed intake and enhanced mobilization of body reserves.

Key Words: Sow, Feeding behavior, Tropical Climate, Lactation, Dietary Protein,

Efeitos do nível de proteína da dieta e da suplementação de aminacidos sobre o comportamento alimentar de porcas multiparas lactantes em clima tropical humido

Resumo – 47 porcas, Large White, de diferentes ordens de parto foram usadas para determinar os efeitos de dietas com redução do conteudo de PB ou suplmentadas com AA industriais sobre o comportamento alimentar das mesmas durante um perido de 28-d de lactação sob condições de clima tropical umido. Este experimento foi conduzido em Guadeloupe (uma ilha da França no Mar do Caribe, lat 16°N, long 61°W) entre fevereiro 2007 e janeiro 2008. Duas estações foram determinadas a posteriori dos dados climaticos obtidos dentro das maternidades. As temperturas médias, minima e maxima e a umidade relativa diaria para a estação morna foram 20,5 e 28,2°C, respectivamente e 93,8%. Os valores correspondentes para a estação quente foram 22,7 e 29,4°C, e 93,7%. Os tratamentos foram assim constituidos: nivel de proteina normal (PN; 17,3%), baixa proteina (BP; 14,1%) e a dieta PN suplementada com AA essenciais (PN+; 17,6%). As dietas PN e BP supriram os mesmos niveis de lisina digestivel (0,80 g/MJ de EL) e a dieta PN+ supriu 0,95 g/MJ de EL. Nenhuma interação entre estação e dieta foi observado. O consumo de raçao diario foi menor (P<0,01) durante a estação quente (4,84 vs. 5,81 kg/d). As porcas alimentadas com a dieta BP mostraram um consumo maior quando comparado com PN e PN+ (+11%; P<0,05), consequentemente, este maior CRD resultou em (não significativo) menores perdas de massa corporal e espessura de toucinho. O numero de refeições por dia nao foi afetado pela estação ou pela composição da dieta. O tamanho da refeição foi reduzido durante a estação quente (757 vs. 542 g/refeição; P<0,01). As porcas alimentadas com as dietas BP apresentaram um tamanho de refeição maior (+127 g/refeição; P<0,10) quando comparado com as outras duas dietas. A proporção de ingestão não foi afetado pela estação ou composição da dieta, mas foi reduzida durante a estação quente (108 vs. 111 g/min). O tempo de ingestão diario (45,5 vs. 55,8 min/d; P<0,05) foi mais baixo na estação quente quando comparado com a estação morna. O tamanho da refeição foi significativamente menor na estação quente durante a noite (533 vs. 707 g por refeição; P<0,01). Na estação morna e quente, CRD, ingestão de alimento, e a proporção de alimento ingerido foram significativamente menores durante o perido noturno do que no periodo diurno (P<0,05). A diferença entre a estação quente e morna foi menos acentuada para o consumo noturno (-296 vs. -846 g/d, respectivamente para noturno e diurno). A duração da atividade em pé não foi afetado pela dieta ou estação, e teve em media 126 min/d. Este estudo confirma que ocorrem alterações no padrão alimentar durante a estação

quente como forma de atenuar os efeitos da temperatura elevada e da alta umidade. Independente da estação, a redução no conteudo de proteina pode attenuar os efeitos do estress sobre o consumo de ração através do aumento do tamanho da refeição.
Key Words: Porca, Comportamento alimentar, Clima tropical, Lactação, Proteina da dieta

Introduction

Ambient temperature and relative humidity are the major environmental factors that affect performance of lactating sows in tropical climate regions. In tropical conditions, because of opened or semi opened buildings, animals are more directly exposed to daily variation of the outside climatic conditions (Renaudeau et al., 2003). When ambient temperature increases above the thermoneutral zone (i.e. above 18-20°C), voluntary feed intake is reduced in order to reduce heat production due to the thermic effect of feed (TEF). The reduction in feed intake is shown to have subsequent 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. Voluntary feed intake (VFI) can be influenced by numerous factors, the most important being related to climatic factors. Different authors have shown that ambient temperature has an important and critical role in regulation of VFI. In controlled climatic rooms with low relative humidity and constant daily temperatures, Quiniou et al. (2000a) reported a curvilinear reduction of feed intake when temperature rose above 22°C with an accentuated reduction of meal size and meal number above 27°C. In another study, these authors also demonstrated that daily fluctuating temperature has smaller effects on VFI than constant daily temperature in connection with an adaptation of feeding behavior (Quiniou et al., 2000b).

According to the net energy system (Noblet et al., 1994), ME from starch and fat is more efficiently used than that of proteins. Consequently, diets with reduced crude protein content and (or) supplemented with amino acids result in lower heat production (Le Bellego et al., 2001). It can then be hypothesized that such diets would be better tolerated in tropical climate conditions. Some results obtained in growing pigs or in lactating sows support this hypothesis (Johnston et al., 1999; Renaudeau et al., 2001 and 2002; and Spencer et al., 2005).

Most previous studies have focused on the effect of elevated temperature on average daily feed intake and lactation performance. Studies on the changes in feeding behavior associated with the reduction of voluntary feed intake under hot conditions are limited. The aim of the present study was then to evaluate the effects of diets with reduced TEF or supplemented with an AA complement on the performance and the feeding behavior of multiparous lactating sows in tropical climate conditions. Results on performance of 89 sows were published in a previous study (Silva et al., 2008). The present paper will focus on the feeding behavior aspects of the study obtained on a sub group of 47 multiparous sows.

Materials and Methods

Experimental Design

A total of 47 multiparous Large White sows in 10 successive replicates of eight to ten animals were used in a trial conducted at the INRA experimental facilities in Guadeloupe, French West Indies (Latitude 16°N, Longitude 61°W); characterized as a tropical humid climate area (Berbigier, 1988). This study covered the period between February 2007 and January 2008.

Within each replicate, sows were distributed in a completely randomized experimental design between three dietary treatments according to backfat thickness, parity order and BW after farrowing. The dietary experimental treatments were: a normal protein diet (NP), a low protein diet (LP) and a NP diet supplemented with an amino acid (AA) complement (NP+). The experimental diets (Table 17) 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 levels of standardized digestible lysine (i.e., 0.80 g/MJ of NE) and the NP+ diet supplied 0.95 g/MJ of NE. For the calculation of the AA complement composition, the lysine content level was increased until the first essential AA became limiting (i.e., phenylalanine + tyrosine), after synthetic AAs were added to maintain a constant ratio between the essential AAs and lysine. Practically, every 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 18. Diets were offered as pellets. Feeds were prepared for one or two successive replicates and stored in a temperature-controlled room (24°C, 50-60% relative humidity).

Animal Management

Sows management and feeding strategies were previously given (Silva et al., 2008). Variations in ambient temperature, relative humidity, and photoperiod closely followed

Table 14 - Composition of the lactation diets, as fed

Item	NP	LP	AAs complement[1]
Ingredients, g/kg			
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 HCL	0.020	0.415	29.6
DL-Methionine	-	0.109	17.3
L-Threonine	-	0.175	19.8
L-Tryptophane	-	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[2]	1.1	1.1	-

[1] AAs complement calculation: lysine content was increased in the NP diet until the other essential AAs (phen + tyr, his, arg, leuc) become limiting following the NRC recommendations for AA/lysine: 111, 39, 55, 110, for phen + tyr, hist, arg, leuc, respectively. For the calculations of the AA complement an estimated ADFI of 5000 g/d was used. 53 g of the AA complement was offered daily to each NP+ sow.
[2] Minerals and vitamins mixture supplied (g/kg of diet): 10 of Cu (as $CuSo_4$); 80 of Fe (as $FeSO_4.7H_2O$); 40 of Mn (as MnO); 100 of Zn (as ZnO); 0.6 of I (as $Ca(IO_3)2$); 0.10 of CO (as $CoSO_4.7H_2O$); 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 thiamin; 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.

outdoor conditions. After birth, piglets were handled for tooth cutting, umbilical cord treatment and labeling. On d 3, they received an intramuscular injection of 200 mg of iron dextran. If necessary, cross-fostering was realized within the first 48 h after birth to standardize litter size to 10 or 11 piglets. Piglets were weighed at birth, 14, 21 and 28 of lactation. On d 14, male piglets were castrated. After 21 days 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 days 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 diagnosis using an ultrasonography (Agroscan, E.C.M., Angoulême, France).

Measurements and Chemical Analyses

Sow and litters measurements were previously described in Silva et al. (2008). Individual feeding behavior was recorded during the *ad libitum* period, i.e. between days 6 and 27, using an electronic trough connected to a load cell and a computer. When the

Table 15 - Analyzed chemical composition of the lactation diets, % DM basis

Analyzed composition	NP	LP	NP+
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,[1] %	4.52	5.37	4.83
Calculated Nutritional Value[2]			
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] [Percentage of tryptophan/(% isoleucine + % leucine + % valine + % phenylalanine + % tyrosine)] x 100.
[2] NE values was estimated form the chemical composition 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 INRA Tables (Sauvant et al., 2003).

trough was detected as being unsteady by the load cell, 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, every morning refusals were manually collected and weighed at the same time, between 0700 and 0800; 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 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 relative humidity were averaged for each replicate. These data were used to split the total experiment period into two seasons through a principal component 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 lower than 20 g was considered an artifact due to the movements of the sows on the slatted floor, and it was not taken into account for further calculations. Because of electronic problems on 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 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., 2006b) 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 parameters of feeding behavior were calculated for each sow: number of meals per day, feed intake per day (g), total ingestion time per day (i.e., total duration of all the visits, min), total consumption time of feed (i.e., sum of the ingestion time and within-meal interval, min), rate of feed intake (i.e., total feed intake/total ingestion time, g/min) and feed intake per meal (g). For each batch, the sows were distributed among 6 crates that were equipped with the load cells, primiparous sows were not included in the feeding behavior study. The effects of season, diet composition, batch, parity and their interactions on sows and litter performance were tested according to an ANOVA (GLM procedure of SAS, Version 8.1, SAS Inst., Inc., Cary, NC). During the ad libitum period (i.e., between d 6 and 27), a total of 903 daily measurements of feeding behavior parameters were measured on 43 sows. These data pooled per sow on a daily basis were analyzed according to a 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 and 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. The effects of season on the kinetics of feed ingestion were analyzed from generation of contrasts between adjacent hourly values. For all analyses using proc 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.

Results

Main characteristics of both seasons are presented in table 19. During the warm season, ambient temperature and relative humidity averaged 23.6°C and 93.8%. 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 (hh:mm) for warm and hot season respectively.

Performance of multiparous sows measured for the feeding behavior is presented in Table 20. During the complete lactation period (i.e., between d0 and 28), daily feed intake was lower during the hot season (4559 vs. 5713 g/d; $P < 0.01$); this was associated with a lower milk production and a reduced litter growth rate (7349 vs. 8348 g/d and 2102 vs. 2397 g/d, respectively for hot and warm seasons; $P = 0.02$). Daily feed intake was higher for the sows fed LP diet when compared to NP and NP+ (5654 vs. 4876 g/d, respectively; $P < 0.05$). Milk production and litter growth rate were not affected by the diet composition ($P = 0.10$). Since milk production was not changed with diet composition, this higher ADFI with LP diet resulted in numerically lower BW loss (20 vs. 26 kg, respectively; $P > 0.10$) and backfat thickness losses (2.7 vs. 4.0 mm, respectively; $P > 0.10$).

According to the analysis of variance, no interaction was observed between season and diet composition for lactation performance and feeding behavior components. Daily feed intake during the *ad libitum* period (i.e., day 6 to day 26) was affected by season ($P < 0.01$) whereas the feed intake was lower during the hot season than in the warm season (4559 vs. 5713 g/d). The number of meals per day was not significantly affected by season, whereas meal size was reduced during the hot season (542 vs. 757 g/meal; $P < 0.01$; Table 21). The ingestion rate was not affected by season ($P > 0.10$). From this result and according to the low feed intake in hot season the daily ingestion time was lower in the hot than in the warm season (45.5 vs. 55.8 min/d, respectively; $P < 0.05$).

The table 22 shows the effect of light pattern on the feeding behavior in lactating sows. No interaction between season and photoperiod or between diet and photoperiod was observed for all the feeding behavior criteria. On average, the diurnal feed intake represented over 55 % of the total feed intake. The reduction of the nocturnal feed consumption was mainly explained by a reduction of meal size (693 vs. 620 g/meal) whereas meals frequency was not affected (4.3 meals/d on average). The rate of feed intake was significantly higher during the night. This result combined with the low nocturnal feed

Table 16 - Main characteristics of climatic parameters[1]

	Season	
Items	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, (hh: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 06:20 to 18:00h and 05:50 to 18:11, for warm and hot seasons, respectively.

intake explained the lack of photoperiod effect on daily time of consumption (25.6 min/d on average).

Irrespective of the season, nycthemeral pattern of feed intake peaked twice a day. The first and second peaks were observed between 0300 and 0900 and between 1500 and 2100, respectively (Figure 4). The size of the peak differed and the hourly feed intakes were significantly higher ($P < 0.05$) for the warm season compared with the hot season at 0700, 0900, 1000 and 1800. Sows consumed proportionally about 45 and 37% of their total feed intake during the first and the second peaks, respectively for warm and hot season ($P < 0.05$). Even though the effect of season was not significant, the duration of standing activity was numerically higher for the hot season, (146 vs. 107 min/d; $P > 0.10$).

The number of meals per day was not significantly affected by diet composition. The sows fed the LP diet showed a higher meal size (+127 g/meal, $P \leq 0.10$) when compared to the other two diets. Daily feed intake during the *ad libitum* period (i.e., day 6 to day 26) was affected by the LP diet than by the other diets (5654 vs. 4876 g/d). The ingestion rate was not affected by diet composition.

From a comparison of hourly feed intakes or variations from hour to hour (between 2400 and 0200), the nycthemeral pattern of feed intake peaked twice a day for all the three dietary treatments. However, the size of the peak differed and the hourly feed intakes were significantly higher ($P < 0.05$) for the LP sows when compared with the other dietary treatments at 1600 and 1700 (Figure 5). The duration of standing activity was higher for the NP diet, but not significant (151 vs. 114 min/d; $P > 0.10$).

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 were published in a previous paper (Silva et al., 2008). For the whole lactation period, litter growth rate and average daily feed intake recorded in the sub-group of 47 multiparous sows were comparable to the values obtained for the 86 mixed parity sows (2.2 vs. 2.1 kg/d for litter growth; and 4.7 vs. 5.1 kg/d for ADFI, respectively). In addition, the reduction due to 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 to measure feeding behavior were considered representative of all sows used in the trial.

Effect of season on feeding behavior in lactation sows

At constant daily temperatures in temperature-controlled rooms (Quiniou et al., 2000a; Renaudeau et al., 2002), or with experimentally generated nycthemeral fluctuations of daily temperature (Quiniou et al., 2000b) or under natural fluctuating temperatures (Renaudeau et al., 2003; Gourdine et al., 2006; present study), two peaks of feeding activity occur during the day. One peak is observed in the morning (i.e., around sunrise) and the other one in the late afternoon (i.e., before the beginning of the night). Our results, under natural fluctuating temperatures, agree with these observations. Theses observations suggest that feeding pattern activity of lactating sows is mainly driven by light intensity changes in the farrowing room. However, other environmental factors, such as presence of staff, collection of refusals and distribution of feed are partially confounded with light intensity changes and can either attenuate or accentuate this diurnal bimodal pattern (Renaudeau et al., 2003). Our study also showed that feeding pattern was affected by season or more specifically by the daily kinetics of temperature and humidity. According to Renaudeau et al. (2003) who realized a study under the same conditions as ours, the lower feed intake during the hotter period of the day is partly counterbalanced by a higher quantity of feed intake during the fresher periods of the day. During our experiment, the

Table 17 - Effect of season and diet composition on the performance of lactating sows and their litters over a 28-d lactation (least square means)

Variable	Diet			Season		RSD[1]	Statistical Analysis[2]
	NP	LP	NP+	Warm	Hot		
N° of lactations	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	4969	5654	4784	5713	4559	864	D*, S**
Body weight, 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	2281	2264	2203	2397	2102	354	S*
Weaning BW, kg/piglet	7.7	7.4	7.3	7.7	7.2	0.8	
Milk production,[3] g/d	7939	7886	7720	8348	7349	1396	S†

[1] RSD: Residual standard deviation.

[2] From an Generalized Linear Model 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). Statistical significance: ***P* < 0.01*, **P* < 0.05*, †*P* ≤ 0.10*.

[3] 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 dry matter using the equation from Noblet and Etienne et al. (1989).

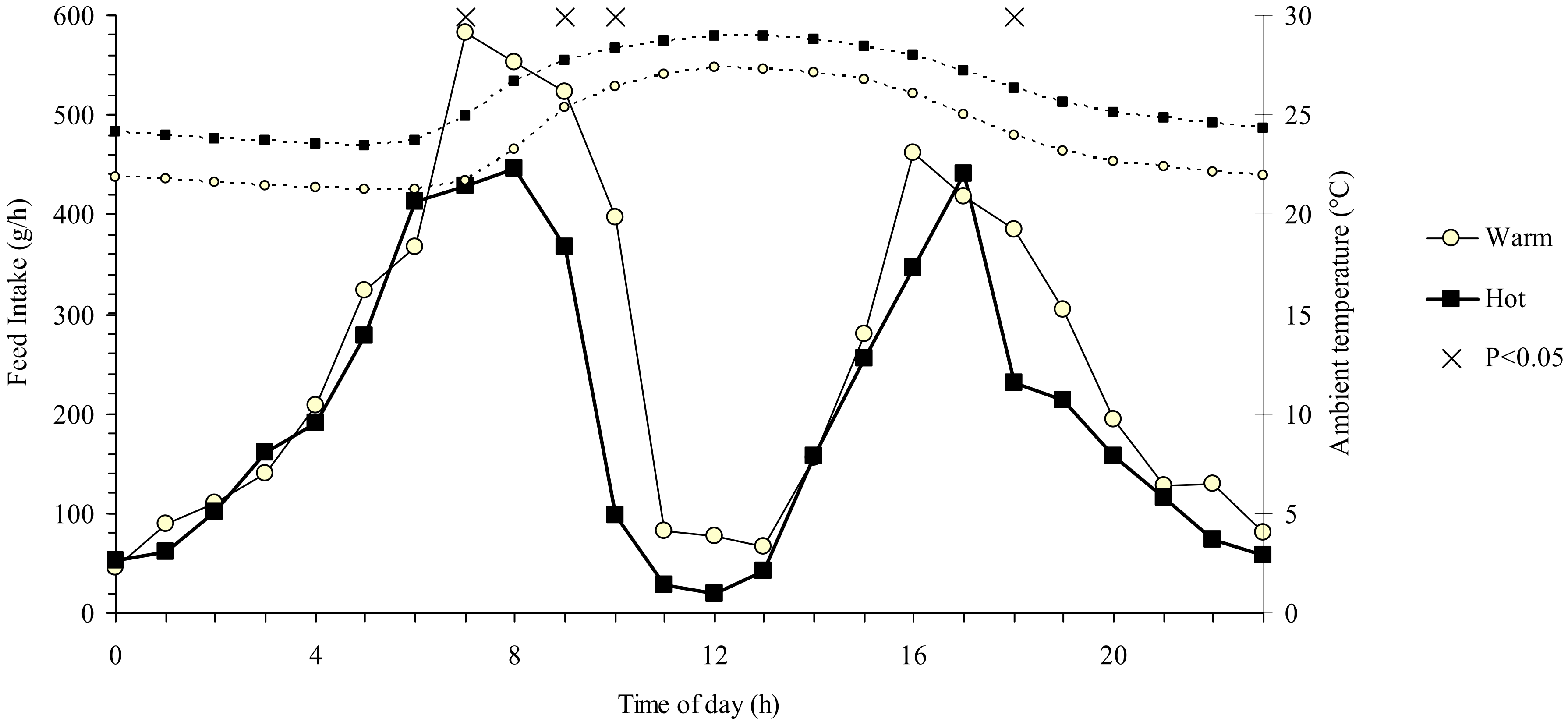

Figure 3 - Effect of season and time of day on the daily fluctuations of ambient temperature (dotted lines) and the kinetics of daily feed intake in lactating sows (solid lines); each point is the least-square mean of 18 sows in the warm season and 29 sows in the hot season. ×: hourly feed consumption was significantly (*P < 0.05*) affected by season.

sows were unable to increase nocturnal consumption. In contrast to Gourdine et al. (2006b), which reported that more than half of the total daily feed intake occurred during the nocturnal period during the hot season (i.e., 64%), in our study we observed that 44% of daily feed intake occurred during the nocturnal period and this value was higher in the hot season than in the warm season (47%). This difference observed in our study can be related to the fact that the ambient temperatures during our trial in the hot season were lower than the ones reported by the later authors (in average 26 vs. 28°C), which lead to better conditions for our sows to have a higher feed intake during the diurnal period (i.e., 53%). In a general way, these results indicate that climatic conditions can also influence the nycthemeral feeding pattern in lactating sows.

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

During the warm season, the daily number of meals averaged 8.1 between day 6 and day 26, which is similar with the value obtained by Renaudeau et al. (2003) between day 6 and day 27 (i.e., 8.8 meals per day). However, meal size was slightly lower in our study (i.e., 649 vs. 718 g per meal). According to Renaudeau et al. (2003) and Gourdine et al. (2006), the decrease in daily feed intake in the hot season was achieved by a significant reduction of meal size in our study (i.e., -215 g per meal) while the number of meals remained constant. No significant effect of season on rate of feed intake was observed in the present study, which is in agreement with results obtained for sows by Quiniou et al. (2000b), Renaudeau et al. (2003) and Gourdine et al. (2006). Subsequently, the decrease of daily feed intake in the hot season was associated with a reduced ingestion time (i.e., 55.8 vs. 45.5 min per day, respectively for warm and hot season; $P < 0.05$).

Effect of dietary treatment on feeding behavior in lactating sows.

Whatever the season considered, except for daily feed intake and meal size, the diet composition did not have effects on all other feeding behavior components. It did not affect as well sow and litter performance which is in agreement with results reported by

Table 18 - Effect of season and diet composition on feeding behavior and duration of standing of lactating sows between d 6 and d 26 postpartum (least square means)

	Diet			Season			
Variable	NP	LP	NP+	Warm	Hot	RSD[1]	Statistical Analysis[2]
N° of lactations	16	16	15	18	29		
Number of meals per day	8.7	8.1	9.5	8.1	9.4	2.7	
Feed intake, g/day	4969a	5654b	4784a	5713	4559	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,[3] min/d	151	112	117	107	146	73	

[1] RSD: Residual standard deviation.

[2] From an Generalized Linear Model 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. Statistical significance: $**P < 0.01$, $*P < 0.05$, $†P \leq 0.10$. Within a line, adjusted means values with different superscripts are significantly different ($P < 0.05$).

[3] Standing duration values include time dedicated for feed consumption and correspond to the means of available values.

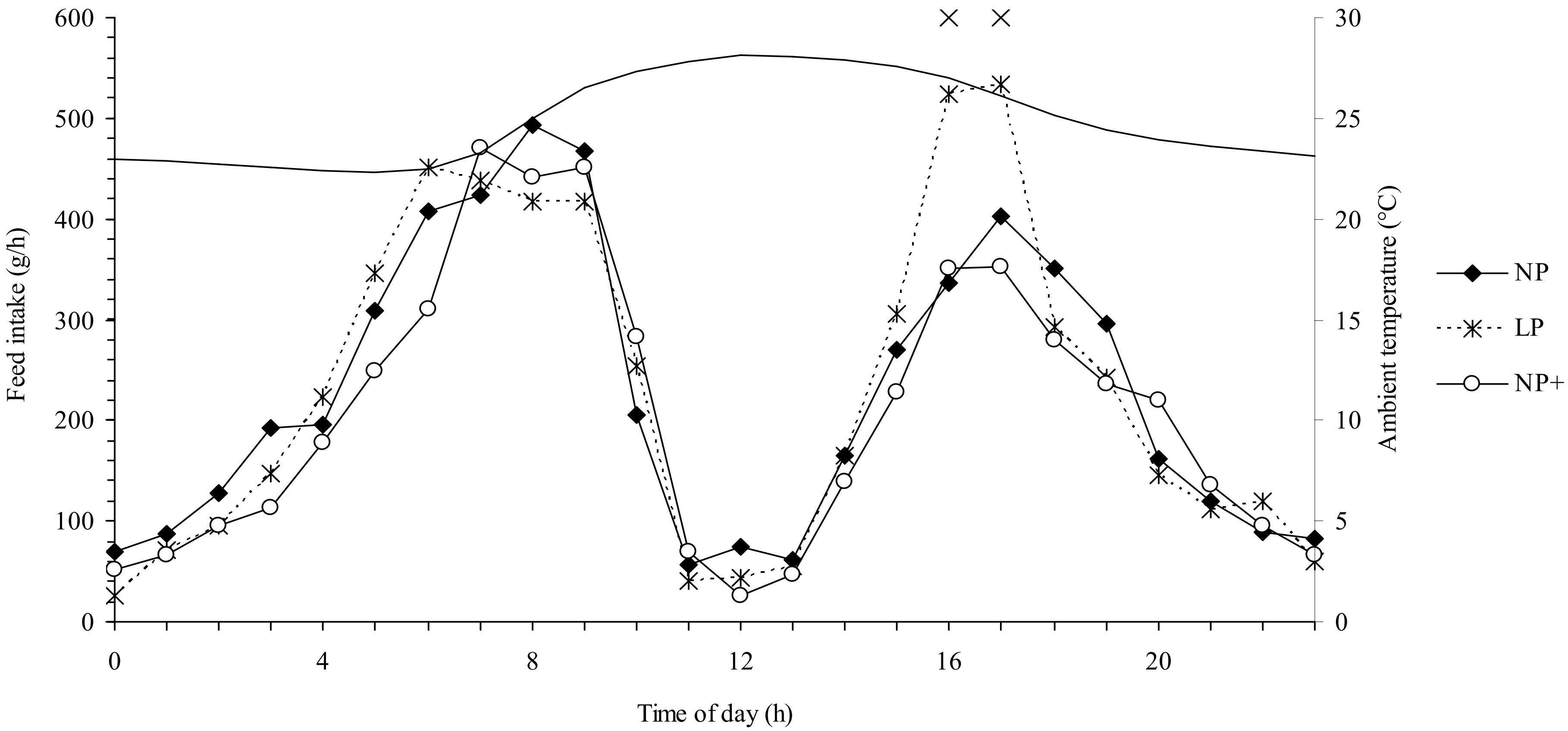

Figure 4 - Effect of diet composition and time of day on the kinetics of daily feed intake in lactating sows; each point is the least-square mean of 16, 16, and 15 sows in the NP, LP and NP+ diets, respectively. × Hourly feed consumption was significantly (*P < 0.05*) affected by diet.

Renaudeau et al. (2002). The higher daily feed intake observed for the sows fed LP diet was associated to a higher 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 to heat stress via an increase of meal size. These results are in agreement with Renaudeau et al. (2002) who reported a higher meal size for the sows fed the LP diet when compared with sows fed a normal protein diet at 29°C (i.e., 730 vs. 643 g per 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 increment. According to the fact that rate of feed intake is not affected by dietary treatment, theses results suggests that the larger meal size in LP could be related to its low heat increment.

The higher feed intake for LP sows was explained by an increase of feed consumption during the second peak of feeding. In the afternoon, the feed consumption seemed to be limited by the ambient temperature combined with high RH. It can be suggested that a decrease of dietary heat increment using LP diet can lead to increase feed consumption. In contrast, NP and NP+ sows were not able to compensate feed intake during the afternoon because of the limiting effects of the higher heat increment of the diet.

The sows fed the NP+ diet showed a higher numerical number of meals per day whereas feed intake and meal size where lower than for the other diets (i.e., -527 g/d and -137 g/meal; respectively). To our knowledge, little is published on the effect of amino acid supplement on the feeding behavior in lactating sows. An increased ratio of tryptophan:LNAA (TRP/ LNAA) is reported to increase linearly the appetite (Henry et al., 1992; Henry and Sève, 1993). Trottier and Easter (1995) reported that a reduction in the TRP:LNAA ratio according to a dietary addition of LNAA decreased feed intake of lactating sows. In our experimental conditions, the TRP/LNAA ratio was quite similar between NP and NP+ diet and could explain the lack of effect of amino acid supplementation on the feeding behavior.

Table 19 - Effect of season and diet composition and light pattern on feeding behavior and duration of standing of lactating sows between d 6 and d 26 postpartum (least square means)

Variable	Diet			Season		RSD[1]	Statistical Analysis[2]
	NP	LP	NP+	Warm	Hot		
N° of lactations	16	16	15	18	29		
Number of meals per day							
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	2710a	3158b	2670a	3266	2426	679	D*, S***, L**,G*
Night	2260a	2496b	2115b	2448	2138		
Diurnal proportion of feed intake,%	55	56	55	57	53	10	DxS†
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		

[1] RSD: Residual standard deviation.

[2] From an Generalized Linear Model 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. Statistical significance: $^{**}P < 0.01$, $^{*}P < 0.05$, $^{\dagger}P \leq 0.10$. Within a line, adjusted means values with different superscripts are significantly different (P < 0.05).

Conclusions

The present study confirms that in tropical conditions, lactating sows are continuously heat stressed and, consequently, their performance and voluntary feed intake are always limited by the climatic factors. Moreover, our results suggest that changes in the feeding pattern occur during the hot season in order to attenuate the effect of elevated temperature and high relative humidity on these changes. Irrespective of season, the reduction of crude protein content can attenuate the effect of heat stress of feed intake via an increase of 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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FINAL CONCLUSIONS

In tropical regions, production and performance remain generally lower than those obtained in temperate countries in Western Europe and North America. Although many factors can be involved, climatic factors are the first most limiting factors of production efficiency in these warm regions. While heat stress is only an occasional challenge during summer heat waves in temperate climate, it is a constant problem in many tropical and subtropical areas. In addition, in these regions, the effects of high ambient temperature can be accentuated by a high relative humidity.

The higher performance potential of present sows tends to generate a higher susceptibility to heat stress. According to the increase of pig production in tropical and subtropical regions, environmental modifications and nutritional strategies can improve the nutrients intake of sows under heat stress and improve their performance. Several management techniques have been tested but only a few ones were found effective and economical in minimizing the impact of heat stress in pig production. These solutions include management strategy to increase animal heat losses by cooling the floor under the sow. The use of low increment diets or high-density diets can effectively attenuate the effect of heat stress in lactating sows but only when diets are correctly balanced for AA to energy ratio. Some changes in the feeding management can also be efficient to enhance productivity of sows in hot conditions. However, optimal pig production under heat stress requires an appropriate combination of nutritional and environmental management solutions.