

PAULO HENRIQUE REIS FURTADO CAMPOS

**EFFECT OF ACCLIMATION TO HIGH AMBIENT TEMPERATURE
OF PIGS SELECTED FOR RESIDUAL FEED INTAKE**

Dissertation 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
Magister Scientiae.

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BIOGRAPHY

PAULO HENRIQUE REIS FURTADO CAMPOS, son of Adelmo Furtado Campos and Maria do Carmo Reis Furtado Campos, born in Belo Horizonte, MG, Brazil, on the 24th of December of 1984.

In February of 2005, initiated at the Universidade Federal de Viçosa (UFV - Brazil) the course in Animal Science and concluded in July of 2009.

In August of 2009, began the MSc studies in Animal Science, in the area of Animal Bioclimatology, at the UFV, and partially (six months) at the *Institut National de la Recherche Agronomique* (INRA – France), submitting the thesis on the 18th of July of 2011.

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RESUMO

CAMPOS, Paulo Henrique Reis Furtado, M.Sc., Universidade Federal de Viçosa, Julho de 2011. **Efeito da aclimação a altas temperaturas em suínos selecionados para consumo residual.** Orientadora: Rita Flávia Miranda de Oliveira Donzele. Coorientadores: Juarez Lopes Donzele e Aloízio Soares Ferreira.

Trinta e seis suínos machos castrados, Large White, pertencentes a duas linhas genéticas divergentes no consumo alimentar residual, com peso inicial de $50,5 \pm 0,9$ kg e aproximadamente 92 dias de idade, foram utilizados para avaliar os efeitos da aclimação ao calor no desempenho, nas respostas termorregulatórias e nos parâmetros sanguíneos de suínos selecionados para alto e baixo consumo residual. O experimento foi conduzido em dois ensaios consecutivos de 18 animais. O primeiro ensaio foi composto por dez animais pertencentes à linha de baixo consumo residual e por oito pertencentes à linha de alto consumo residual e, o segundo ensaio, foi composto por nove animais de cada linha genética. Os suínos foram alojados em uma sala climatizada na qual a temperatura ambiente foi mantida em $24,2 \pm 0,4^{\circ}\text{C}$ durante os primeiros sete dias do experimento e, posteriormente, mantida em $30,4 \pm 0,7^{\circ}\text{C}$ durante 14 dias. O aumento da temperatura da sala ocorreu no oitavo dia do experimento em um intervalo de tempo de três horas. Os animais foram pesados no início, no oitavo e no vigésimo primeiro dia do experimento. O consumo de ração foi determinado diariamente com base na diferença entre a quantidade de alimento fornecido e a quantidade de sobras. Animais com baixo consumo alimentar residual consumiram menos ração, tiveram menor consumo metabólico, melhor eficiência alimentar e ganho de peso similar aos animais de alto consumo alimentar residual. O consumo de ração diário, consumo metabólico de ração, ganho de peso diário e a eficiência alimentar diminuíram no ambiente de calor. A temperatura retal não foi influenciada pela linha genética, no entanto foi maior a 30°C . A temperatura cutânea e a frequência respiratória não diferiram entre as linhas genéticas em ambiente termoneutro, no entanto, foi observado um aumento desses parâmetros com o aumento da temperatura ambiental, sendo este aumento superior na linha de alto consumo alimentar residual. Maiores valores de frequência cardíaca foram observados em animais de alto consumo residual e também em ambiente termoneutro. Amostras de sangue foram coletadas, por meio de cateteres, para mensurar os hormônios

tireoidianos, glicose, glicerol, α -aminoácidos, lactato, hematócrito, insulina, IGF-I e leptina. A concentração plasmática de lactato foi superior nos animais de alto consumo residual. Maiores níveis de insulina e menores níveis de hormônios tireoidianos foram observados em ambiente de calor em ambas linhas genéticas. Conclui-se que os efeitos negativos das altas temperaturas ambientais são menos pronunciados em suínos de baixo consumo residual e que estes necessitam de uma menor ativação dos mecanismos termorregulatórios para manter a homeotermia em ambiente de calor quando comparados à suínos de alto consumo residual.

ABSTRACT

CAMPOS, Paulo Henrique Reis Furtado, M.Sc., Universidade Federal de Viçosa, July of 2011. **Effect of acclimation to high ambient temperature of pigs selected for residual feed intake.** Adviser: Rita Flávia Miranda de Oliveira Donzele. Co-Advisers: Juarez Lopes Donzele and Aloízio Soares Ferreira.

Thirty-six Large White castrate males belonging to two divergent lines in residual feed intake, with average initial body weight of 50.5 ± 0.9 kg and approximately 92 days of age, were used to evaluate the effects of acclimation to high temperature on the performance, thermoregulatory responses and blood parameters of pigs divergently selected for low and high residual feed intake. The experiment was conducted in two successive replicates of 18 animals each. The first replicate was composed by ten animals with low residual feed intake and eight animals with high residual feed intake and, the second one, was composed by nine animals of each line. Pigs were housed in a climatic-controlled room where the ambient temperature was maintained at $24.2 \pm 0.4^\circ\text{C}$ during the first seven days and thereafter at $30.4 \pm 0.7^\circ\text{C}$ during 14 days. The temperature change was achieved over three hours on the eighth day of the experiment. Pigs were individually weighed at the beginning, on the eighth and on the twenty-first day of the experiment. Feed intake was daily determined by the difference between the feed allowance and refusals. Low residual feed intake pigs consumed less feed ($P < 0.001$), had lower metabolic average daily feed intake ($P < 0.001$), higher gain:feed ratio ($P < 0.001$) and similar body weight gain ($P > 0.05$) than high residual feed intake pigs. Average daily feed intake, metabolic average daily feed intake, average daily gain, and gain:feed ratio were lower ($P < 0.001$) at 30°C than at 24°C . Rectal temperature was not influenced by line ($P > 0.05$), whereas it was higher ($P < 0.001$) at 30°C . Cutaneous body temperature and respiratory rate were similar for both lines at termoneutrality and increased with the ambient temperature increase, with a higher increase being observed in the RFI+ line ($P < 0.001$). Heart rate was higher ($P < 0.05$) in RFI+ line and higher ($P < 0.001$) at 24°C . Blood samples were collected via catheters to measure thyroid hormones, glucose, glicerol, α -amino acids, lactate, hematocrit and plasma concentrations of insulin, IGF-I and leptin. Plasma lactate concentration was higher in RFI+ pigs than in RFI- ($P < 0.01$). Higher levels of insulin

($P < 0.05$) and lower concentration of thyroid hormones ($P < 0.001$) were observed at high ambient temperatures. In conclusion, this study suggests that RFI- pigs tended to be less negatively affected by high ambient temperature and also require a lower activation of thermoregulatory mechanisms to maintain homeothermy in hot conditions than RFI+ pigs.

INTRODUCTION

According to FAO estimates approximately 925 million people in the world are undernourished and global food demand is projected to grow 70.0% by 2050. This increased demand for food supply has highlighted the importance of increasing meat production and in enhancing the efficiency of conversion of feed into high-value animal protein.

Most of the genetic trends that have been used in breeding programs to evaluate feed efficiency (e.g. feed conversion ratio, partial growth efficiency and relative growth rate) are expressed as ratio of feed intake to product. The use of these trends present problems associated with prediction of the expected future changes in the component traits for the next generations (Hoque and Suzuki, 2009). Additionally, the use of feed conversion (gain: feed ratio) implies in some problems once it is highly correlated to growth stage and body weight. Therefore, two animals that differ in feed intake and growth rates could have a similar feed conversion ratio (Fan et al., 2010).

Residual feed intake has been recognized as a biological trait more suitable for evaluating feed efficiency in production animals because it is phenotypically independent of stage of growth and body size (Fan et al., 2010; Hoque and Suzuki, 2009), being recently used in experimental selection programs in pigs (Gilbert et al., 2007; Cai et al., 2008; Sellier et al., 2010). Residual feed intake represents the fraction of total feed intake that is unexplained by maintenance and production requirements of an animal. This trait allows comparison between individuals differing in level of production (Hoque and Suzuki, 2009) and the selection of more efficient animals without correlated changes in the production traits (Gilbert et al., 2007).

Although breeding programs have focused on the selection of efficient pigs, special attention should also be given to the selection of animals more adapted to hot climatic conditions. Still according to FAO predictions pig production will rapidly increase in developing countries to supply the global demand for food. However, most of these countries are located in tropical or subtropical regions where the heat stress remains one of the major problems that affect the efficiency of pig production (Silva et al., 2009).

Pigs under heat stress (i.e. ambient temperature above 25°C for growing pigs) reduce their appetite in order to reduce their heat production due to the thermal effect of feed. This reduction in feed intake is dependent on animal related factors such as body weight, gender, breed and environmental factors such as housing, feeding regimes and the climatic conditions. The decreased feed consumption has negative consequences on pigs' performance (i.e lower body weight gain) which implicates in economic losses (Renaudeau et al., 2004).

In order to reduce the undesirable effects of high ambient temperatures on the performance, some nutritional and environmental alternatives have been tested (Le Bellego et al., 2002; Sartor, 1999) However, the nutritional strategies have not been completely able to attenuate the negative effects of heat stress (Le Bellego et al., 2002) and the management strategies are usually expensive, thus not economically feasible in most cases. Nevertheless, genetic selection for heat-tolerant animals has been recently suggested as an alternative for pig production in high temperature regions (Renaudeau et al., 2004). This strategy would allow the selection of animals whose performance is not negatively affected in a pronounced way under high ambient temperatures, via selecting animals with higher thermolysis capacity and/or decreased heat production (Renaudeau et al., 2004).

Some studies have demonstrated that low residual feed intake animals have a decreased total heat production (Barea et al., 2010) and tend to be more adapted to high ambient temperatures. Thus, selection for low residual feed intake besides increased feed efficiency could also be related to selection of animals more adapted to heat stress, which would allow considerable improvement in pig production in tropical and subtropical regions.

Based on these considerations, this work was carried out with the purpose to evaluate the effects of acclimation to high temperature on the performance, thermoregulatory responses and blood parameters of pigs divergently selected for low and high residual feed intake.

MATERIAL AND METHODS

The experiment was carried out in the experimental facilities of the *Institute National de la Recherche Agronomique* (INRA), France, during the period of August 2010 and January 2011. Care and use of animals were performed according to the certificate of authorization to experiment on living animals issued by the French Ministry of Agriculture.

Animal and experimental design

Thirty-six Large White castrate males, randomly selected, belonging to two divergent lines in residual feed intake, with average initial body weight of 50.5 ± 0.9 kg and approximately 92 days of age, were used. The experiment was conducted in two successive replicates of 18 animals each. The first replicate was composed by ten animals with low residual feed intake (RFI-) and eight animals with high residual feed intake (RFI+). The second replicate was composed by nine animals belonging to the RFI- line and nine belonging to the RFI+ line.

The RFI- and RFI+ lines had, respectively, a lower and a greater feed consumption relative to the feed intake predicted from their performance. These animals originated from a divergent selection experiment for RFI conducted at INRA over seven generations since 2000. This experiment produced two different lines of animals with the same performance levels, similar growth and body composition, but with different RFI. The details of this selection program have been previously described by Gilbert et al. (2007).

Housing, experimental procedure and experimental diet

Two weeks before the beginning of the experiment pigs were moved to the climatic-controlled room to adapt to the experimental conditions (housing, diet and management). During this adaptation period the temperature of the room was maintained at 24°C.

The climatic-controlled room was equipped with 18 individual metal-slatted pens. Each pen was equipped with a feed dispenser and a nipple drinker designed to avoid water and feed spillage. The photoperiod was fixed to 12h of artificial light (0800 to 2000 h).

During the experimental period, pigs were kept at 24°C for seven days (period 1 – P1; from day 1 to 7), and thereafter at 30°C for 14 days (period 2 – P2; from day 8 to 21). On day 8, the temperature was changed gradually from 24°C to 30°C at a constant rate of 2°C/ h beginning at 1000 h and ending at 1300 h (Figure 1).

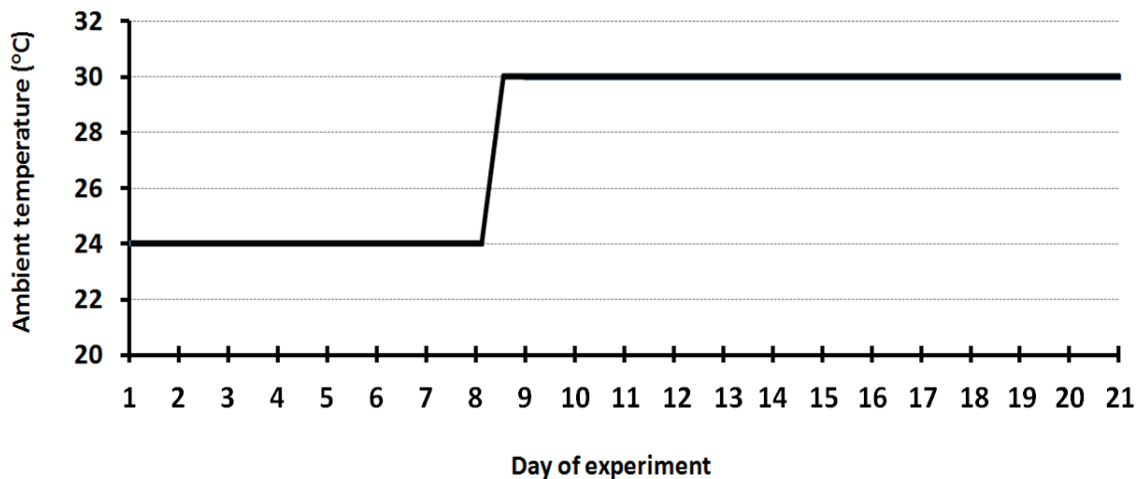


Figure 1. Environmental temperature during the experimental period.

Temperature and humidity of the room were registered each five minutes using a data logger placed in the center of the room and these data were used to estimate the

temperature-humidity index, according to Buffington et al. (1982). Relative humidity was not controlled.

Pigs had free access to water and feed. The diet was formulated to meet the nutritional requirements of this animal category according the recommendations of InraPorc software (Table 1).

Surgery

A total of ten pigs/line (four pigs/line in the first replicate and six pigs/line in the second one) were randomly selected and surgically operated two weeks before the beginning of the experiment. After 24-h fasting, under general anesthesia (Fluothane, Belamont, France), an indwelling catheter was inserted through a collateral vein in the right external jugular vein according the methodology described by Melchior et al. (2004). The catheter was tunneled under the skin and externalized on the back of the animal. Except during blood sampling, the catheter was stored in a strengthened purse sewed on the skin of the pig. The surgical operation did not exceed 20 - 30 min/ pig. Every two to three days, the catheters were flushed with five ml of normal saline solution containing 5.0% of heparin.

Measurements and sample collection

Pigs were individually weighed at the beginning and at the end of the experiment, and an additional weighing was realized on the morning of day 8, before the change of temperature.

Every morning, between 0800 and 0830 h, feed refusals were collected, and fresh feed was immediately distributed, except on the days when blood samplings were realized, where the animals were submitted to two hours fasting. Feed intake was determined as the difference between the feed allowance and the refusals collected the next day. Every day, one sample of feed refusals of each animal was collected. The samples were pooled per period (P1 and P2), and then dry matter (DM) content was measured. Samples of the fresh feed were also taken every day and similarly pooled for DM determination and chemical analysis of dietary composition.

Rectal temperature (RT), cutaneous body temperatures (CT), respiratory rate (RR) and heart rate (HR) were measured in all pigs twice daily (0830 and 1500 h) on days 2, 4, 7, 8, 10, 11, 14, 16 and 18 of experiment. On day 8 (day of temperature transition from 24°C to 30°C), the same physiological parameters were performed each hour, from 0900 till 1400. Also on day 8, the physiological measurements were performed only on animals without catheters so that there would be no influence on blood samples.

The measurements were carried out according the following protocol: first, RR was visually determined by counting flank movements over a period of one min, only in resting pigs. After RR measurements were completed, HR was measured using a heart rate monitor. Following, RT was measured using a digital thermometer (Microlife Corp., Paris, France). Afterwards, CT was measured on the back and flank using a digital thermometer (HH-21 model, Omega Engineering Inc., Stamford, CT) with a K probe. During the measurements the position of the animals was also registered (lying, sitting or standing) and their condition (calm or stressed).

Blood samples were collected via catheters on days 3, 7, 8, 10, 11, 15 and 21 in order to measure the thyroid hormones, glucose, glicerol, α -amino acids, lactate,

hematocrit and plasma concentrations of insulin, IGF-I and leptin. For each sampling, the following protocol was applied. Before the blood sampling, approximately five ml of blood was taken and thrown away in order to eliminate dilution from the heparin block. Afterwards, 20 ml of blood was collected using heparinized tubes kept in ice until centrifugation. Finally, five ml of saline solution with heparin was injected to prevent the development of blood clots. The collected tubes were centrifuged during ten minutes at 3,000 rpm at 4°C (refrigerated centrifuge) and plasma was immediately subdivided in subsamples and stored at -20°C or -80°C in function of the type of analyzes to be performed.

The blood samples were performed two hours after the feed refusals were collected, between 1030 and 1100 h. The feeders were refilled once the blood sampling was completed. This procedure was carried out during the morning with the animals fasted for a period of two hours, except on day 8. On that day, the blood samplings were performed each hour, from 0900 till 1400 h and at 1800 h and the animals were not submitted to fasting. Also on day 8, blood energetic metabolites were not analyzed once the animals were not submitted to a fasting period.

Chemical Analyses

Feed samples of each period were analyzed for DM, ash, fat contents and CP (N x 6.25) according to the AOAC (1990). Gross energy (GE) content was measured using an adiabatic bomb calorimeter (IKA, Staufen, Germany). Digestible energy (DE), metabolizable energy (ME) and net energy (NE) were estimated from GE content based on DE:GE, ME:DE and NE:ME ratio estimated by EvaPIG® software. Feed crude

fibers contents and cell wall components (neutral detergent fiber, acid detergent fiber and acid detergent lignin) were determined according to Van Soest et al. (1991).

Plasma glucose, lactate, glycerol and α -amino acids were analyzed on a multianalyzer Konelab 20 apparatus (Thermo Electron Corporation, Cergy Pontoise, France). To perform α -amino acids analysis, plasma samples were previously deproteinized with trichloroacetic acid and centrifuged. Plasma IGF-I concentrations were determined using a validated radioimmunoassay (Louveau and Bonneau, 1996) that used recombinant human IGF-I (GroPep, Adelaïde, Australia). Thyroid hormones were determined using T3 solid phase component system kit and T4 monoclonal solid phase RIA kit (MP Biomedicals, Orangeburg, U.S.A). Commercial RIA kits were used to measure plasma concentration of insulin (CIS Bio International, Gif sur Yvette, France) and leptin (Millipore Corp., Billerica, U.S.A).

Calculations and statistical analysis

Because of problems during feed management on day 3, feed consumption data of this day was not considered in the analyses. Due to feed spillage, performance data of one animal RFI- was removed from the analyses.

For each pig, daily feed intake (ADFI in g of DM or in g of DM/kg^{0.60}; Noblet et al., 1999), ADG (g/d), G:F (DM gain/intake) and the average of the physiological parameters (RT, CT, RR and HR) were calculated for both temperatures (24 and 30°C). These data were analyzed using the MIXED procedures of SAS (SAS Inst., Inc., Cary, NC) including the effects of line, period and their interaction. Replicate and pig were considered as a random effect. To reflect the dependence of the data obtained on the same animal at different periods of measurements, were utilized a compound symmetry

and a heterogeneous compound symmetry matrix type for performance and physiological parameters, respectively. The effects of ambient temperature on the kinetics of metabolic ADFI responses were analyzed using the same model. Least squares means for the effects were computed and the differences between the effects of levels were tested with a Tukey test (PDIFF option in the LSMEANS statement). Differences were considered significant at $P < 0.05$.

Table 1. Composition, nutritional levels and energy values of the experimental diet.

Ingredients, %	
Corn	25.39
Wheat	23.00
Barley	23.00
Soybean meal	18.70
Molasses	2.00
Wheat bran	5.00
Dicalcium phosphate	1.10
Calcium carbonate	0.70
Salt	0.40
L-Lysine HCL	0.18
L-Threonine	0.03
Vitamins and trace minerals mixture ¹	0.50
Nutritional levels (%) ^{2, 3}	
Dry matter	87.01
Ash	5.58
Crude protein	18.31
Fat	2.31
Starch	51.36
Neutral detergent fiber	14.21
Acid detergent fiber	4.85
Acid detergent lignin	0.70
Lysine	0.91
Digestible lysine	0.80
Threonine	0.62
Digestible threonine	0.52
Energy values ³ (MJ/kg DM)	
Gross energy	18.16
Digestible energy	15.24
Metabolizable energy	14.61
Net energy	10.88

¹Vitamins and minerals mixture supplied per kilogram of diet: 5,000 IU of vitamin A; 1,000 IU of vitamin D₃; 20 mg of vitamin E; 2 mg of vitamin B₁; 4 mg of vitamin B₂; 10.85 mg of calcium pantothenate; 15 mg of niacin; 0.02 mg of vitamin B₁₂; 1 mg of vitamin B₆; 2 mg of vitamin K₃; 1 mg of folic acid; 0.2 mg of biotin; 500 mg of choline chloride; 56 mg of Fe_(sulfate); 24 mg of Fe_(carbonate); 10 mg of Cu_(sulfate); 100 mg of Zn_(oxide); 40 mg of Mn_(oxide); 0.2 mg of I_(iodate); 0.1 mg of Co_(carbonate); 0.15 mg of Se_(selenite).

²Values expressed in dry matter basis.

³Levels analyzed in laboratory, excepting for lysine, digestible lysine, threonine and digestible threonine whose values were predicted by formulation.

RESULTS

Kinetics of daily mean and variation of the ambient temperature and relative humidity over the experiment are presented in figure 2. During the period 1 (P1), the average ambient temperature was $24.2 \pm 0.4^\circ\text{C}$, the average relative humidity was $49.6 \pm 9.6\%$ and the calculated temperature-humidity index was 70.5 ± 0.4 . During the period 2 (P2), the corresponding values of ambient temperature, relative humidity and temperature-humidity index were $30.4 \pm 0.7^\circ\text{C}$, $36.6 \pm 9.4\%$ and 76.5 ± 0.5 .

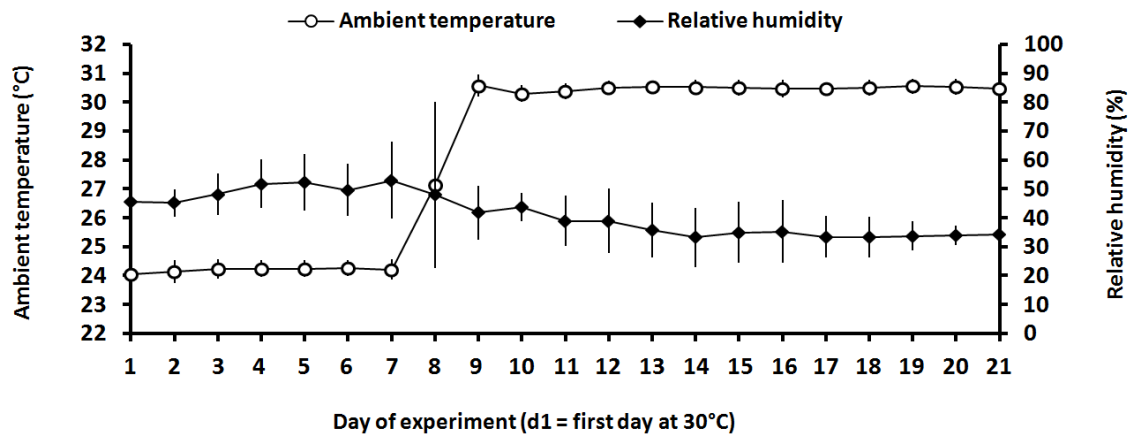


Figure 2. Daily mean and variance of the ambient temperature and relative humidity during the experimental period (means + SE).

Pigs' performance during the experimental period is presented in table 2.

Table 2. Effect of line on performance of growing pigs kept at 24 and 30°C (least squares means).

	24°C		30°C		<i>P</i> -value ²		
	RFI-	RFI+	RFI-	RFI+	T	L	L*T
Initial BW (kg)	49.5 ± 0.9	51.5 ± 0.9	57.3 ± 1.1	59.5 ± 1.1		0.15	
ADG (g/d)	1,104 ± 59	1,148 ± 57	836 ± 44	783 ± 43	<0.001	0.91	0.42
ADFI (g/d) ¹	2,238 ± 85	2,612 ± 83	2,038 ± 55	2,232 ± 54	<0.001	<0.001	0.17
ADFI (g.kg of BW ^{-0.60} .d ⁻¹) ¹	206 ± 6	234 ± 6	169 ± 4	183 ± 4	<0.001	<0.001	0.18
G:F (g of gain/g of feed)	0.49 ± 0.02	0.44 ± 0.02	0.41 ± 0.02	0.35 ± 0.02	<0.001	<0.01	0.86

¹For an average DM of 86.6%.

²Effects of line (L), temperature (T) and their interaction as fixed effects.

No interactions ($P>0.05$) between line and ambient temperature were found for all criteria studied. Average initial body weight in P1 (24°C) and in P2 (30°C) did not differ between lines. As expected average initial body weight in P2 was higher than in P1. Independently of ambient temperature RFI+ pigs had higher daily feed intake than RFI- pigs (2,612 vs. 2,238 g/d in P1 and 2,232 vs. 2,038 g/d in P2; $P<0.001$). When the animals were exposed to high ambient temperatures low feed consumption in both lines was observed (2,238 vs. 2,038 g/d in RFI- and 2,612 vs. 2,232 g/d in RFI+ at 24 and 30°C respectively; $P<0.001$).

Similar results were also observed when daily feed intake was expressed per unit of metabolic BW, with RFI+ line having consumed more feed than RFI- line (234 vs. 206 g.kg of $BW^{-0.60}.d^{-1}$ in P1 and 183 vs. 169 g.kg of $BW^{-0.60}.d^{-1}$ in P2; $P<0.001$), and animals decreasing feed intake in high ambient temperatures (206 vs. 169 g.kg of $BW^{-0.60}.d^{-1}$ in RFI- and 234 vs. 183 g.kg of $BW^{-0.60}.d^{-1}$ in RFI+ at 24 and 30°C respectively; $P<0.001$).

Daily gain was not affected by line, whereas it was affected by ambient temperature ($P<0.001$), being higher at 24°C than at 30°C (1,126 vs. 809 g/d on average).

Gain: feed ratio was affected by line ($P<0.01$) and temperature ($P<0.001$) with a lower G:F in RFI+ line (0.44 vs. 0.49 g/g in P1 and 0.35 vs. 0.41 g/g in P2) and at 30°C (0.49 vs. 0.41 g/g in RFI- line and 0.44 vs. 0.35 in RFI+ line).

Figure 3 represents the kinetics of metabolic feed intake (expressed as g.kg of $BW^{-0.60}.d^{-1}$) during the experimental period for each line. Except on day 2 metabolic, ADFI was not affected by breed ($P>0.05$).

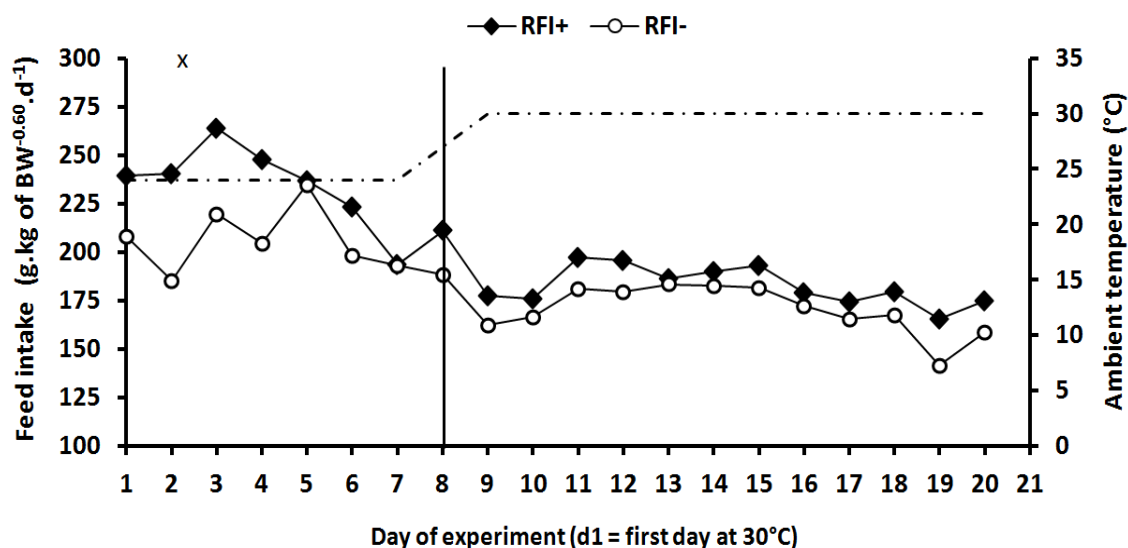


Figure 3. Effect of line on the kinetics of ADFI (g.kg of BW^{-0.60}.d⁻¹) during the experimental period (dotted line = ambient temperature). x = mean value significantly affected by breed (P<0.05).

Thermoregulatory responses of RFI+ and RFI- pigs kept in thermoneutral and hot environment are presented in table 3.

Table 3. Effect of line on thermoregulatory responses of growing pigs kept at 24 and 30°C (least squares means).

	24°C		30°C		P-value ¹		
	RFI-	RFI+	RFI-	RFI+	T	L	L*T
Rectal temperature (°C)	39.6 ± 0.1	39.7 ± 0.1	39.8 ± 0.1	40.0 ± 0.1	<0.001	0.16	0.10
Cutaneous temperature (°C)	37.0 ± 0.1	37.1 ± 0.1	37.8 ± 0.1	38.2 ± 0.1	<0.001	0.04	<0.001
Respiratory rate (bpm)	57 ± 2	53 ± 2	81 ± 2	87 ± 2	<0.001	0.61	<0.001
Heart rate (bpm)	143 ± 3	148 ± 2	131 ± 2	139 ± 2	<0.001	0.04	0.56

¹Effects of line (L), temperature (T) and their interaction as fixed effects.

Rectal temperature was not influenced by line, whereas it was higher in high ambient temperature (39.9 vs. 39.6°C on average at 30 and 24°C, respectively; P<0.001).

Interaction (P<0.001) between line and ambient temperature was found for cutaneous temperature and respiratory rate.

At 24°C cutaneous temperature was similar for both lines. However, when exposed to 30°C both lines showed an increase in cutaneous temperature, being this increase higher in RFI+ pigs.

Similar results were also observed in respiratory rate that increased in both lines under hot environment. At 30°C RFI+ pigs had higher respiratory rate values than RFI- pigs which were not observed at thermoneutrality where respiratory rate did not differ between lines.

Heart rate was affected by line ($P < 0.05$) and temperature ($P < 0.001$) being lower in RFI- line than in RFI+ (143 vs. 148 bpm and 131 vs. 139 bpm in P1 and P2, respectively) and lower at 30°C than at 24°C (131 vs. 143 bpm and 139 vs. 148 in RFI- and RFI+ line, respectively).

Blood parameters of RFI+ and RFI- pigs kept under thermoneutral and hot environment are presented in table 3.

Table 4. Effect of line on blood parameters of growing pigs kept at 24 and 30°C (least squares means).

	24°C		30°C		<i>P</i> -value ¹		
	RFI-	RFI+	RFI-	RFI+	T	L	L*T
Hematocrit (%)	32.25 ± 0.60	31.43 ± 0.65	31.44 ± 0.56	31.76 ± 0.58	0.43	0.76	0.06
Glucose (mg/l)	1058 ± 20	1055 ± 22	1050 ± 17	1033 ± 18	0.25	0.69	0.57
Lactate (mg/l)	82.84 ± 3.62	94.30 ± 3.52	85.38 ± 2.63	99.51 ± 2.70	0.13	<0.01	0.60
Glycerol (mg/l)	3.93 ± 0.31	3.74 ± 0.29	4.09 ± 0.20	4.00 ± 0.21	0.34	0.63	0.83
α-amino-acids (mg/l)	607.4 ± 20.5	645.2 ± 21.6	592.8 ± 17.7	655.1 ± 18.4	0.85	0.06	0.32
IGF-I (ng/ml)	241.6 ± 24.8	264.8 ± 26.7	227.5 ± 23.5	238.5 ± 24.9	0.06	0.62	0.56
Insulin (μUI/ml)	23.12 ± 2.52	21.87 ± 2.64	25.63 ± 2.05	26.80 ± 2.11	0.03	0.99	0.49
T3 (ng/dl)	106.4 ± 5.2	108.0 ± 5.5	82.3 ± 4.7	79.1 ± 4.9	<0.001	0.91	0.40
T4 (μg/dl)	3.36 ± 0.19	3.32 ± 0.20	2.70 ± 0.17	3.01 ± 0.18	<0.001	0.59	0.07
Leptin (ng/ml)	2.76 ± 0.20	2.32 ± 0.21	2.88 ± 0.18	2.47 ± 0.18	0.24	0.11	0.90

¹Effects of line (L), temperature (T) and their interaction as fixed effects.

No interaction ($P > 0.05$) between line and ambient temperature was found for any parameter analyzed.

Hematocrit values and plasma glucose, glycerol, α-amino-acids, IGF-I and leptin concentrations were not affected by line or by ambient temperature.

Plasma lactate concentration was not affected by temperature, but it was higher in RFI+ pigs than in RFI- (96.90 vs. 84.11 mg/l on average; $P < 0.01$). A higher value of plasma insulin concentration was observed under a hot environment (26.22 vs. 22.49 $\mu\text{UI/ml}$ on average; $P < 0.05$). This parameter was not influenced by line.

Thyroid hormones (T3 and T4) showed similar responses and were not affected by line but were lower ($P < 0.001$) in high ambient temperature than at thermoneutrality (80.72 vs. 107.16 ng/dl and 2.85 vs. 3.34 $\mu\text{g/dl}$ on average for T3 and T4, respectively).

DISCUSSION

The present study is one of the unique evaluating the process of acclimation to high ambient temperatures in pigs selected for low (RFI-) or high (RFI+) residual feed intake.

According to Renaudeau et al. (2008) the upper limit temperature of the thermoneutral zone for growing pigs is approximately 25°C. Thus, during the first period of our study pigs were maintained in a thermoneutral environment and thereafter, during the second period, the animals were exposed to high ambient temperatures.

When pigs are exposed to high ambient temperature behavioral, physiological and metabolic adjustments are needed to allow their survival in this challenging environment. Within these adjustments decreased feed consumption, increased respiratory rate and cutaneous temperature could be mentioned (Renaudeau et al., 2007). Alterations in plasma thyroid hormones concentrations are also described in those conditions (Hannas et al., 1999). These thermoregulatory responses that allow the animals maintain their internal temperature constant, which is indispensable for the maintenance of vital processes and functions.

In our study, irrespective of line, each degree increase in ambient temperature resulted in a reduction of 47g/day in average daily feed intake (ADFI). Our result is in accordance with the value estimated from the equation proposed by Quiniou et al. (2000; i.e. 41 g/day/°C) and also in agreement with Le Dividich et al. (1998). These latter authors reported a decreased in feed consumption in the order of 40 to 80 g/day per each degree increased in ambient temperature from a temperature range from 20 to 30°C.

According to Macari et al. (1986), feed intake depends on environmental temperature and the thyroid gland play a crucial role in this process. Thyroid hormones are implicated in the control of heat production in homoeothermic animals and heat acclimation involves a decrease in these hormones levels in order to reduce endogenous heat production (Bernabucci et al., 2010). Therefore, as expected, a decrease in T3 and T4 under hot conditions was reported in our study, with a correlated reduction in feed consumption.

The reduction in feed intake establishes a direct negative impact in pigs performance once the amount of nutrients available for growth decreases. Thus, a reduction of 52.83 g/°C in body weight gain (ADG) was observed in the current study, which is in agreement with the findings of Renaudeau et al. (2008) that reported a reduction of 50 g/day/°C in ADG in growing pigs for a temperature range from 24 to 32°C.

When the pattern of decrease of both ADFI and ADG were compared, the reduction in growth rate was more than twice higher than the reduction in feed consumption (-28 vs. -12%), suggesting that pigs were less efficient to use feed for growth when they were exposed to high temperatures, which is evidenced by the lower values of gain: feed ratio (G: F) during heat stress. Lower feed efficiency in growing pigs maintained in hot environments was also described by Tavares et al. (1999) and Kiefer et al. (2009). According Manno et al. (2006) the negative effects of high ambient temperatures on growth rate are not strictly related with the decrease in feed consumption. In these conditions part of nutrients are redirected to maintain thermoregulatory mechanisms which decrease the efficacy of feed utilization for growth.

Our study also demonstrates an adjustment in thermoregulatory responses during acclimation to increase thermolysis. Under high ambient temperatures a rise in cutaneous temperature and respiratory frequency were observed irrespective of line. The increase in cutaneous temperatures is explained by an enhanced blood volume in the peripheral blood vessels to increase heat exchange between the animal and the environment by the sensible pathway. However, with the increase in ambient temperature the pigs ability to lose heat by the sensible pathway reduces due to a reduction in the gradient of temperature between the skin and the ambient (Quiniou et al., 2000). Thus, in an ambient temperature above 28°C, almost all heat loss in growing pigs is accomplished through the evaporative pathway (Renaudeau et al., 2008). Taking into account the limited number of sweat glands that limits the cutaneous evaporative capacity in pigs, the respiratory rate is the most important via of evaporative losses in pigs (Silva et al., 2009), which results in its higher rates during heat stress. Higher values of skin temperature and respiratory rate under hot conditions were also reported by Manno et al. (2006) and Kiefer et al. (2009), both evaluating the effects of the environmental temperature on the growth performance of pigs. Likewise, Renaudeau et al. (2008), found an increase in cutaneous temperature (+1.2°C) and respiratory rate (+48 breaths/ min.) in growing pigs for a temperature range from 24 to 32°C.

Similar pattern of responses was also described for rectal temperature that was higher at 30°C than at 24°C for both lines. An increase in this parameter was also reported by Renaudeau et al. (2008) and Kiefer et al. (2009) in growing pigs maintained at 36 and 31°C respectively. According to Renaudeau et al. (2008), a rise in rectal temperature under hot conditions indicates that the thermoregulatory process were not efficient to maintain body homeothermy. Nevertheless, this rise in rectal temperature

can also be considered as a part of the pigs mechanism to maintain a temperature gradient between core and skin temperature.

Little information is available concerning the influence of ambient temperature in heart rate of growing pigs. In the current study, this trait decreased when the ambient temperature increased from 24 to 30°C. This fact could be explained as an attempt of the body to reduce heat production related with heart activity. In addition, lower heart rate could also be associated with a reduction in the metabolism under hot conditions, which is supported by the results of plasma thyroid hormones concentrations obtained in our study that also decreased at 30°C.

Ambient temperature also influenced plasma levels of insulin that were higher at 30°C than at 24°C. Despite the role of insulin on thermogenesis is still not well described (Silva, 2006), a possible explanation for that consists in a loss of binding ability of insulin receptors under high ambient temperatures, which could be attributed to the accelerated degradation of receptors and/or to a transitory and reversible non-binding state that occurs during heat stress (Zacharyus et al., 1996). Although not significant, plasma IGF-I concentrations tended to be lower at 30°C. This fact may be associated with the lower feed consumption under heat stress once plasma IGF-I concentration is mainly dependant on nutritional status of the pig (Clemmons et al., 1991), with levels being closely related to the energy intake (Dauncey et al., 1990).

Selection for low RFI improves feed efficiency without correlated effect on growth rate, in spite of the reduction in voluntary feed consumption (Hoque and Suzuki, 2009). Our study is in accordance with this statement and demonstrates higher feed efficiency and lower feed consumption in RFI- pigs without differences on growth rate, irrespective with the period evaluated. These findings are also in accordance with

previous studies performed with animals from the same breeding program of the present study (Gilbert et al., 2007; Barea et al., 2010).

When the kinetics of feed intake (expressed as $\text{g.kg of BW}^{-0.60}.\text{d}^{-1}$; figure 3) was analyzed, although it was observed line effect only on day 2, the metabolic feed intake of RFI+ pigs was numerically higher in all experimental days, confirming the tendency of these animals to consume more feed irrespective of the period evaluated. An explanation for the no effect of line consists in the fact that when analyzed per day the power to detect statistical significance was lower due to the small number of observations.

The biological basis of variation in RFI is not completely understood. In broad terms it is due to numerous intrinsic factors such as variation in feed digestibility, in basal metabolic rate, energy utilization and physical activity (Haer et al., 1993; Herd and Arthur, 2009). Mitochondrial efficiency has been considered as one source of genetic variation in energetic efficiency in mice (McDonald et al., 2009) poultry (Ojano-Dirain et al., 2007; Bottje and Carstens, 2009) and steers (Kolath et al., 2006), however, little information is available on growing pigs. Differences in the efficacy to capture energy from substrates has been associated with variations in mitochondrial efficiency, with less efficient cells losing more energy as heat in the process to transform energy from substrate in ATP (Silva, 2006). In our study, lactate plasma concentrations were higher in RFI+ pigs, however, based on our knowledge, no comparable information is available in literature, which limits our understanding in this regard.

Barea et al. (2010), in a pioneer study evaluating the relationship between RFI and digestibility coefficients and energy partitioning in growing pigs, observed that total heat production was greater in RFI+ than in RFI- pigs. This difference was mainly

associated with greater basal metabolic rate and increased physical activity in RFI+ pigs which results in animals energetically less efficient.

According to Renaudeau et al. (2004), the capacity to adapt to a hot environment is inherent of each animal. These authors reported that animals with lower basal heat production, lower physical activity and lower production of heat associated with the utilization of feed tend to be more adapted to high temperatures. On that sense we were expecting a higher capacity of low residual feed intake (RFI-) pigs to adapt to high ambient temperatures than high residual feed intake (RFI+) pigs.

Although no interaction was found between line and ambient temperature for any performance trait, ADFI of RFI+ pigs decreased 14.0% when these animals were exposed to high temperatures compared with a decrease of 9.0% in RFI- pigs. This pattern of response were also described for ADG and G: F, in which the first one decreased 31.0% in the RFI+ line compared with a decrease of 24.0% in the RFI- line, and the second one decreased 20.0% and 16.0% in the RFI+ and RFI- line, respectively. These findings indicate that RFI- pigs tended to be less negatively affected than RFI+ by high ambient temperature, which is supported by the results obtained for thermoregulatory responses.

Under hot conditions, RFI+ pigs had a significantly higher increase in cutaneous temperature (+1.1 vs. +0.8°C) and respiratory rate (+34 vs. +24 breaths/ min.) than RFI- pigs. The higher activation of the thermoregulatory mechanisms observed in RFI+ pigs during acclimation demonstrates the higher need of these animals to lose heat to the environment to maintain homeothermy when compared with RFI- pigs, which is consistent with the higher heat production of RFI+ pigs reported by Barea et al. (2010) and Frances et al. (unpublished data).

Contrary to our expectations were not observed interactions between line and ambient temperature for any sanguine parameters studied. We were expecting higher decrease in plasma leptin levels in RFI+ line under heat stress, which was not observed. According to Lefaucheur et al. (2011), leptin plasma concentration is mainly related with differences in body composition, which may explain our results. Despite no interaction between line and ambient temperature, RFI+ pigs had a numerically higher decrease in plasma T3 concentrations than RFI- (-26.0% vs. -22.0%), these results are consistent with the ones obtained for ADFI, and once again reinforces the role of this hormone in feed intake control.

CONCLUSIONS

This study suggests that RFI- pigs tended to be less negatively affected by high ambient temperature and also require a lower activation of thermoregulatory mechanisms to maintain homeothermy in hot conditions when compared with RFI+ pigs.

REFERENCES

- Association of Official Analytical Chemistry - AOAC. **Official methods of analysis**. 15.ed. Arlington, VA: Association of Official Analytical Chemists, 1990.
- Barea, R.; Dubois, S.; Gilbert, H.; Sellier, P.; Van Milgen, J.; Noblet, J. Energy utilization in pigs selected for high and low residual feed intake. **Journal of Animal Science**, v. 88, n. 6, p. 2062-2072, 2010.
- Bernabucci, U.; Lacetera, N.; Baumgard, L.H.; Rhoads, R.P.; Ronchi, B.; Nardone, A. Metabolic and hormonal acclimation to heat stress in domesticated ruminants. **Animal**, v. 4, n. 7, p. 1167-1183, 2010.
- Bottje, W.G.; Carstens, G.E. Association of mitochondrial function and feed efficiency in poultry and livestock species. **Journal of Animal Science**, v. 87, n. 14 Suppl, p. E48-63, 2009.
- Buffington, D.E.; Collier, R.J.; Canton, G.H. Shade management systems to reduce heat stress for dairy cows. **Transactions of the American Society of Agricultural Engineers**, n. 26, p. 1798-1802, 1983.
- Cai, W.; Casey, D.S.; Dekkers, J.C. Selection response and genetic parameters for residual feed intake in Yorkshire swine. **Journal of Animal Science**, v. 86, n. 2, p. 287-98, 2008.
- Clemmons, D.R.; Underwood, L.E. Nutritional regulation of IGF-I and IGF binding proteins. **Annual Review of Nutrition**, v. 11, p. 393-412, 1991.
- Dauncey, M.J. Thyroid hormones and thermogenesis. **Proceedings of the Nutrition Society**, v. 49, n. 2, p. 203-15, 1990.
- De Haer, L.C.M.; Luiting, P.; Aarts, H.L.M. Relations among individual (residual) feed intake, growth performance and feed intake pattern of growing pigs in group housing. **Livestock Production Science**, v. 36, n. 3, p. 233-253, 1993.
- Fan, B.; Lkhagvadorj, S.; Cai, W.; Young, J.; Smith, R.M.; Dekkers, J.C.; Huff-Lonergan, E.; Lonergan, S.M.; Rothschild, M.F. Identification of genetic markers associated with residual feed intake and meat quality traits in the pig. **Meat Science**, v. 84, n. 4, p. 645-50, 2010.

- Gilbert, H.; Bidanel, J.P.; Gruand, J.; Caritez, J.C.; Billon, Y.; Guillouet, P.; Lagant, H.; Noblet, J.; Sellier, P. Genetic parameters for residual feed intake in growing pigs, with emphasis on genetic relationships with carcass and meat quality traits. **Journal of Animal Science**, v. 85, n. 12, p. 3182-8, 2007.
- Hannas, M.I.. Aspectos fisiológicos e a produção de suínos em clima quente. In. SILVA, I.J.O (Ed.) **Ambiência e qualidade na produção industrial de suínos**. Piracicaba: Fundação de Estudos Agrários Luiz de Queiroz, 1999. p. 01-33.
- Herd, R.M.; Arthur, P.F. Physiological basis for residual feed intake. **Journal of Animal Science**, v. 87, n. 14, p. E64-71, 2009.
- Hoque, M.A.; Suzuki, K. Genetics of residual feed intake in cattle and pigs: A review. **Asian-Australasian Journal of Animal Sciences**, v. 22, n. 5, p. 747-755, 2009.
- Kiefer, C.; Meignen, B.C.G.; Sanches, J.F.; Carrijo, A.S. Response of growing swine maintained in different thermal environments. **Archivos de Zootecnia**, v. 58, n. 221, p. 55-64, 2009.
- Kolath, W.H.; Kerley, M.S.; Golden, J.W.; Keisler, D.H. The relationship between mitochondrial function and residual feed intake in Angus steers. **Journal of Animal Science**, v. 84, n. 4, p. 861-865, 2006.
- Le Bellego, L.; Van Milgen, J.; Noblet, J. Effect of high temperature and low-protein diets on the performance of growing-finishing pigs. **Journal of Animal Science**, v. 80, n. 3, p. 691-701, 2002.
- Le Dividich J.; Noblet J.; Herpin P.; van Milgen J; Quiniou N. Thermoregulation. In: **Progress in Pig Science** (ed. J Wiseman, MA Varley and JP Chadwick). Nottingham University Press, Nottingham, 1998, p. 229-263.
- Lefaucheur, L.; Lebret, B.; Ecolan, P.; Louveau, I.; Damon, M.; Prunier, A.; Billon, Y.; Sellier, P.; Gilbert, H. Muscle characteristics and meat quality traits are affected by divergent selection on residual feed intake in pigs. **Journal of Animal Science**, v. 89, n. 4, p. 996-1010, 2011.
- Louveau, I.; Bonneau, M. Effect of a growth hormone infusion an plasma insulin-like growth factor-1 in Meishan and Large White pigs. **Reproduction Nutrition Development**, v. 36, n. 3, p. 301-310, 1996.

- Macari, M.; Zuim, S.M.; Secato, E.R.; Guerreiro, J.R. Effects of ambient temperature and thyroid hormones on food intake by pigs. **Physiology & Behavior**, v. 36, n. 6, p. 1035-9, 1986.
- Manno, M.C.; Oliveira, R.F.M.; Donzele, J.L.; Oliveira, W.P.; Vaz, R.G.M.V.; Silva, B.A.N.; Saraiva, E.P.; Lima, K.R.S. Effects of environmental temperature on performance of pigs from 30 to 60 kg live weight. **Revista Brasileira de Zootecnia**, v. 35, n. 2, p. 471-477, 2006.
- Mcdonald, J. M.; Ramsey, J. J.; Miner, J. L.; Nielsen, M. K. Differences in mitochondrial efficiency between lines of mice divergently selected for heat loss. **Journal of Animal Science**, v. 87, n. 10, p. 3105-3113, 2009.
- Melchior, D.; Sève, B.; Le Floc'h, N. Chronic lung inflammation affects plasma amino acid concentrations in pigs. **Journal of Animal Science**, v. 82, n. 4, p. 1091-1099, 2004.
- Noblet, J.; Karege, C.; Dubois, S.; Van Milgen, J. Metabolic utilization of energy and maintenance requirements in growing pigs: Effects of sex and genotype. **Journal of Animal Science**, v. 77, n. 5, p. 1208-1216, 1999.
- Ojano-Dirain, C.P.; Pumford, N.R.; Toyomizu, M.; Bottje, W.G. Association of mitochondrial function and feed efficiency. **Journal of Poultry Science**, v. 44, n. 3, p. 221-237, 2007.
- Quiniou, N.; Dubois, S.; Noblet, J. Voluntary feed intake and feeding behaviour of group-housed growing pigs are affected by ambient temperature and body weight. **Livestock Production Science**, v. 63, n. 3, p. 245-253, 2000.
- Renaudeau, D.; Hue, E.; Noblet, J. Acclimation to high ambient temperature in Large White and Caribbean Creole growing pigs. **Journal of Animal Science**, v. 85, n. 3, p. 779-790, 2007.
- Renaudeau, D.; Kerdoncuff, M.; Anais, C.; Gourdine, J.L. Effect of temperature level on thermal acclimation in Large White growing pigs. **Animal**, v. 2, n. 11, p. 1619-1626, 2008.
- Renaudeau, D.; Mandonnet, N.; Tixier-Boichard, M.; Noblet, J.; Bidanel, J. P. Attenuate the effects of high ambient temperature on pig performance: The genetic selection. **Productions Animales**, v. 17, n. 2, p. 93-108, 2004.

- Sartor V.; Baeta F.C.; Ferreira A.S.; Cecon P.R.; Tinoco I.F.F. Effect of the systems of evaporative cooling in the performance of lactation sows and their litters. **Engenharia Agricola**, v. 18, p. 4-13, 1999.
- Sellier, P.; Billon, Y.; Riquet, J.; Lagant, H.; Calderon, J.A.; Guillouet, P.; Bidanel, J.P.; Noblet J.; Gilbert, H. Six générations de sélection divergente pour la consommation journalière résiduelle chez le porc en croissance: Réponses corrélatives sur les caractères de reproduction des truies et synthèse des réponses sur les caractéristiques de production. **Journées de la Recherche Porcine**, v. 42, p. 167–172, 2010.
- Silva, B.A.N.; Noblet, J.; Donzele, J.L.; Oliveira, R.F.M.; Primot, Y.; Gourdine, J.L.; Renaudeau, D. Effects of dietary protein level and amino acid supplementation on performance of mixed-parity lactating sows in a tropical humid climate. **Journal of Animal Science**, v. 87, n. 12, p. 4003-4012, 2009.
- Silva, J.E. Thermogenic mechanisms and their hormonal regulation. **Physiological Reviews**, v. 86, n. 2, p. 435-464, 2006.
- Statistical Analysis Software - SAS. SAS/STAT 9.1 **User's Guide**. SAS Institute Inc., Cary, NC, USA, 2004.
- Tavares, S.L.D.S.; Oliveira, R.F.M.; Donzele, J.L.; Ferreira, A.S. Influence of the environmental temperature on the performance and on the physiological parameters of female piglets from 30 to 60 kg. **Revista Brasileira de Zootecnia**, v. 28, n. 4, p. 791-798, 1999.
- Van Soest, P.J.; Robertson, J.B.; Lewis, B.A. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. **Journal of Dairy Science**, v. 74, n. 10, p. 3583-3597, 1991.
- Zacharyus, J.L.; Benatmane, S.; Plas, C. Role of Hsp70 synthesis in the fate of the insulin-receptor complex after heat shock in cultured fetal hepatocytes. **Journal of Cellular Biochemistry**, v. 61, n. 2, p. 216-229, 1996.