Anim. Res. 50 (2001) 507–521

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Original article

Effects of tropical climate and season on growth, chemical composition of muscle and adipose tissue and meat quality in pigs

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(Received 20 July 1999; accepted 5 November 2001)

Abstract — The effects of tropical climate and season on growth performance, meat quality and chemical composition of muscle and adipose tissue were determined on ad libitum fed Large White pigs. Individually housed animals placed in a tropical climate in a semi-open room were compared to those kept in a climatic room at constant 20 °C and 75% relative humidity (control climate, CC). During the cool season in the tropical climate (CTC), the ambient temperature averaged 24.8 ± 3.6 °C and relative humidity was 83 ± 14%. Corresponding figures for the warm season in the tropical climate (WTC) were 27.9 ± 3.0 °C and 81 ± 12%, respectively. The voluntary feed intake (VFI) of animals reared in CTC weighing between 35 and 94 kg decreased by 9% ($P < 0.001$), as compared to CC. In WTC, VFI of the 35 to 94 kg animals decreased by 13% ($P < 0.001$) and average daily gain by 12% ($P < 0.01$), as compared to CC, whereas their carcasses were leaner at slaughter ($P < 0.05$). Ultimate pH of muscles *longissimus dorsi* ($P < 0.01$) and *biceps femoris* ($P < 0.05$) was higher in the tropical climate than in CC whereas moisture loss of the *biceps femoris* and *semispinalis* muscles was lower ($P < 0.05$). The lipid content of leaf fat declined in WTC ($P < 0.05$), as compared to CC. Exposition to the tropical climate resulted in a lower lipid content of the outer layer of backfat ($P < 0.05$) and a higher degree of unsaturation of fat in the entire backfat ($P < 0.01$), as compared to CC. Neither the chemical composition of backfat inner layer and M. *longissimus dorsi* nor the degree of unsaturation of lipids in the latter were significantly altered by the environment. The results suggest that tropical climate may have a favourable influence on pork quality.

growing pig / tropical environment / skeletal muscle / adipose tissue / meat quality

Résumé — **Influence du climat tropical et de la saison sur la composition chimique des muscles et des tissus adipeux et la qualité de viande du porc en croissance.** Un essai a été mené pour déterminer les effets du climat tropical sur les performances de croissance, la composition chimique des muscles et des tissus adipeux et la qualité de la viande de porcs Large White. Au total 40 femelles

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et mâles castrés ont été nourris ad libitum et logés en cage individuelle entre 15 et 94 kg de poids vif. Les porcs placés en climat tropical dans une salle semi-ouverte ont été comparés aux témoins élevés dans une salle à ambiance contrôlée dans laquelle la température ambiante a été maintenue constamment à 20 °C et l'humidité relative (Hr) à 75 %. Les mesures réalisées dans la salle semi-ouverte au niveau des animaux indiquent qu'en climat tropical en saison chaude la température ambiante est en moyenne de 27,9 ± 9,3 °C et l'Hr de 81 ± 12 %. Les chiffres correspondant en saison fraîche sont de 24,8 ± 3,6 °C et de 83 ± 14%, respectivement. En saison fraîche en climat tropical le niveau d'ingestion spontané d'aliment des porcs entre 35 et 94 kg de poids vif décroît de 9 %, relativement aux témoins. Chez le porc de 35 à 94 kg de poids vif, une diminution de 13 % de la quantité d'aliment consommé ($P < 0,001$) et de 12 % du gain de poids ($P < 0,01$) est observée en saison chaude en climat tropical sans modification significative de l'indice de consommation, par rapport aux témoins. Les porcs élevés en saison chaude en climat tropical sont les plus maigres ($P < 0,05$). Le pH ultime des muscles *longissimus dorsi* ($P < 0,01$) et *biceps femoris* ($P < 0,05$) est plus élevé en climat tropical que dans une ambiance de 20 °C et 75 % d'Hr alors que les pertes en eau des muscles *biceps femoris* et *semispinalis* sont plus faibles ($P < 0,05$). Les plus faibles teneurs en lipides d'un tissu adipeux interne, la panne, sont observées en climat tropical pendant la saison chaude ($P < 0,05$). Indépendamment de la saison, chez les porcs élevés en climat tropical, la teneur en lipides d'un tissu adipeux sous-cutané, la couche externe de la bardière, décroît par rapport au milieu témoin ($P < 0,05$), et le coefficient d'insaturation des lipides de la bardière entière est plus élevé ($P < 0,01$) que chez les témoins. Ni la composition chimique de la couche interne de la bardière et du muscle *longissimus dorsi* ni le degré d'insaturation des lipides de ce muscle ne sont significativement affectés par les conditions environnementales. Nos résultats suggèrent que le climat tropical pourrait avoir une influence favorable sur la qualité technologique et nutritionnelle de la viande de porc.

porc en croissance/ climat tropical / muscle / tissu adipeux / qualité de viande

1. INTRODUCTION

In the tropics, the quality of pig meat from locally reared animals is often assumed to be better than that imported from temperate areas, even when pigs are fed similar diets based on cereals. This might be attributed, at least partly, to the climate which is characterised in the Caribbean area by both high ambient temperature and relative humidity. Pork quality is well known to be highly dependent on various factors such as breed, sex, slaughter weight and feeding conditions [2, 10, 34, 37]. Studies on young 20–30 kg pigs have shown that a high ambient temperature in the range of 31.5–35 °C induces a general slowing down in the metabolism of skeletal muscle and adipose tissue and modifies the chemical composition of fat [6, 27]. A few studies have assessed the influence of constant [18] or fluctuating [3, 19] high ambient temperature on meat quality and the characteristics of adipose tissue and muscles of pigs slaughtered at 90–105 kg body weight. A constant ambient temperature of 28 °C had favourable effects on the following characteristics, as compared to 12 °C: meat quality linked to higher ultimate pH in white muscle, lower lipid content of red muscle and unsaturation of lipids in backfat [18]. However, no change was observed in meat quality as assessed by colour, marbling and firmness of the M. *longissimus dorsi* area in ad libitum fed pigs exposed to a cycling ambient temperature of 27–35 °C in comparison to animals housed at temperatures in the range of 18 to 21 °C [3, 19]. There is also a lack of information on the influence of environmental conditions on the fatty acid composition of lipids in muscle. The effect of an actual tropical climate on meat quality has not yet been investigated. The present trial was designed to determine whether the effects of tropical climate and season on growth performance are concomitant with

changes in the chemical composition of muscle and adipose tissue and meat quality in Large White pigs.

2. MATERIALS AND METHODS

This experiment was conducted in Guadeloupe (French West Indies, 16° Lat. N., 61° Long. W.) to establish the effects of tropical climate and season on the performance and characteristics of muscle and adipose tissue in Large White growing pigs fed ad libitum, as compared to a control environment. To do this, two climatic treatments were used: a tropical climate vs. a constant relative humidity (RH) of 75% and air temperature of 20 °C. A temperature of 20 °C was chosen because it is within the temperature range recommended for maximum average daily gain [11, 25]. The two climatic treatments were compared both during the cool season, from November to February, and during the warm season, from April to October.

2.1. Experimental procedure, feeding and housing

A total of 40 individually housed castrates and females were fed ad libitum from 14.7 ± 1.8 kg live weight to slaughter at 93.5 ± 2.5 kg. Two commercial diets, which are the conventional diets available in Guadeloupe, were used and their chemical composition is shown in Table I. Pigs were fed diet 1 from 15 to 35 kg live weight and diet 2

Table I. Composition ($g \cdot kg^{-1}$ diet) of the two experimental diets given to the 15 to 35 kg body weight (BW) pigs (diet 1) and to the 35 to 94 kg BW pigs (diet 2).

	Diet 1	Diet 2
Measured by chemical analysis:		
Dry matter	885	881
Crude protein	186	168
NDF	98	127
ADF	31	40
Crude fat	39	39
Fatty acids:		
C14:0	0.6	0.1
C16:0	7.6	6.8
C16:1	0.5	0.3
C18:0	1.6	1.2
C18:1	8.3	9.0
C18:2	18.5	19.9
C18:3	1.5	1.4
C20:0	–	–
C20:1	0.8	–
Assessed by calculation[1]:		
Lysine	11.4	8.5
Methione + cystine	7.0	5.7
Threonine	7.3	6.0
Tryptophan	2.4	1.9
Metabolisable energy ($MJ \cdot kg^{-1}$)	13.26	12.74

[1] Calculations were made on the basis of the composition of the ingredients of the feed.

from 35 kg to slaughter. The metabolisable energy (ME) and crude protein contents of diet 1 were respectively 13.3 MJ·kg^{-1} and 18.6% and diet 2 provided 12.7 MJ ME·kg^{-1} and 16.8% of crude protein. The pigs had free access to water using a nipple water drinker. For each of the two seasons, five litters were weaned simultaneously at 28 ± 2 d of age. Within each litter, four animals, two castrates and two females, were chosen and entered the experimental building. One castrate and one female per litter were placed in a tropical climate and the other two littermates in a climatic room at 20 °C, 75% RH until slaughter. Pigs were assigned to one of the two climatic treatments to get a complete balanced block design, according to litter origin, sex and live weight.

The animals reared under the tropical climate were placed in a semi-open room in which the air temperature and RH were continuously recorded using probes located at the level of the pigs. On the day the control animals entered the climatic room, the air temperature was set at 28 °C and RH at 75%. The RH remained unchanged until the end of the trial whereas air temperature was gradually reduced to 20 °C by the 9th day postweaning and remained constant thereafter. The trial began 5 d later. In the climatic room, which has previously been described by Rinaldo et al. [29], ambient temperature and RH were controlled and regulated within ± 0.5 °C and ± 3%, respectively. The individually penned animals were placed in wired cages with metal slatted floors.

2.2. Measurements and analyses

2.2.1. Performance and carcass traits

The animals were weighed and their voluntary feed intake was determined weekly during the whole experiment. When they reached 93.5 ± 2.5 kg live weight, the pigs were slaughtered after an overnight fast. The animals were weighed, stunned, exsanguinated and eviscerated. The weights of the full and emptied digestive tracts were recorded to calculate the empty body weight. After 24 h chilling at 4 °C, the carcasses were split into halves which were weighed. The left half-carcass was measured for average backfat thickness as a mean of first rib, last rib and last lumbar vertebrae values. This half-carcass was cut into pieces according to the method described by Ollivier [26]. Fat and muscle percentages were assessed from the weights of the left half-carcass and those of fat and lean cuts by using the predicting equation established by Desmoulin et al. [8]. The validity of this equation in the present experimental conditions was checked by comparing the actual fat and muscle percentages measured using the weights of tissues obtained by dissection of the carcasses with those assessed using the equation. This comparison was carried out during the warm season on a total of 12 pigs, half of which were housed in the control room and the others in the tropical climate. Whatever the climatic treatment, no significant difference was found between the actual and assessed fat and muscle percentages. The equation found by Desmoulin et al. [8] was thus considered as valid in tropical conditions and used to determine the carcass traits of the pigs.

2.2.2. Feed analyses

Feed samples were pooled weekly and analysed for dry matter content. Their protein content was estimated from nitrogen (N × 6.25) measured by the Kjeldahl method. Neutral Detergent Fibre (NDF) and Acid Detergent Fibre (ADF) contents were determined according to Van Soest et al. [35]. Total lipids were extracted according to Folch et al. [12]. Fatty acid methyl esters were prepared with boron fluoride methanol according to Morrison and Smith [22] and analysed on a Di 200 gas chromatograph (Delsi, Paris, France) (capillary column CW 20 M, temperature: 180 °C, hydrogen pressure: 0.5 bar), using margaric acid as an

internal standard. The oven, detector and injector temperatures were maintained at 180, 240 and 220 °C, respectively. Retention time and peak areas were determined using ordinat software (Nelson Analytical, Inc., San Jose, USA).

2.2.3. Meat quality and measurements on muscle and adipose tissue

Meat quality criteria and chemical composition of muscle and adipose tissue were determined on a total of 32 animals, i.e. 8 pigs per climatic treatment within each of the two seasons.

Meat quality criteria were determined on the following three muscles: M. *semispinalis*, M. *longissimus dorsi* at the last rib level and M. *biceps femoris*. The pH was measured at 45 min (pH1) and 24 h (pH2) post mortem using a pH meter probe. The water-holding capacity of muscles was determined using the filter paper press method described by Goutefongea [14] and modified by Lefaucheur et al. [18].

Immediately after slaughter, samples of about 10 g of the following adipose tissues were taken on the right half-carcass: leaf fat, outer and inner layers of subcutaneous backfat at the neck level. Samples of about 60 g of M. *semispinalis* and M. *longissimus dorsi* at the last rib level were also taken within 20 min after exsanguination. The tissues were cleaned up. The whole muscle sample and half the sample of adipose tissue were freeze-dried while the remaining adipose tissue was frozen (–18 °C). The dry matter and crude protein (N × 6.25) contents of muscle and adipose tissue were measured on freeze-dried samples. Frozen samples of adipose tissue and freeze-dried samples of muscle were analysed for their fat content and the fatty acid composition of their lipids as previously described for feed. The unsaturation coefficient of lipids was calculated according to Courboulay and Mourot [7].

2.2.4. Statistical analyses

Statistical analyses were carried out by analysis of variance using the general linear model (G.L.M.) procedure of the Statistical Analysis System (S.A.S., 1994) [30]. The effects of climatic treatment, season, sex, the interaction between climatic treatment and season, the interaction between sex and climatic treatment and the interaction between climatic treatment × season × sex were assessed. After making sure that the data obtained for the control treatment did not significantly differ from one season to the other, the data were pooled. There were therefore three environments, either the control treatment, or the cool or warm season in the tropical climate. The adjusted means presented in the tables were calculated by assessing the effects of the environment, sex and the interaction between the environment and sex.

3. RESULTS

3.1. Climatic parameters

Under tropical climate, the average ambient temperature measured at the level of the animals was 27.9 ± 3.0 °C during the warm season and 24.8 ± 3.6 °C during the cool one. The corresponding figures for RH were 81 ± 12% and 83 ± 14%, respectively. According to present data, diurnal variations in both ambient temperature and RH were more marked than seasonal changes. The difference between minimal nocturnal temperature and maximal diurnal temperature was about 6 °C with little variation over the year. Maximal RH was on the average 95 ± 3% during the night time and mean minimal RH was 72 ± 9% around midday. Recorded data showed that in the climatic room average ambient temperature was 20.0 ± 0.5 °C and RH was 75 ± 4%.

3.2. Growth and carcass traits

During the cool season, the tropical climate had no significant effect on the growth

response in 15 to 35 kg pigs, as compared to the control environment (Tab. II). In 35 to 94 kg pigs, the voluntary feed intake (VFI) was 9% lower ($P < 0.01$) in animals reared in the cool season in the tropical climate than in the control pigs and their backfat was thinner ($P < 0.05$). During the warm season in the tropical climate, a 6% decrease in VFI ($P < 0.05$) was observed in 15–35 kg pigs without any change in their average daily gain due to a 0.11 unit improvement in the feed to gain ratio ($P < 0.01$), as compared to the control environment. In heavier pigs, a 13% decline in VFI ($P < 0.001$) during the warm season led to a 12% drop in the average daily gain ($P < 0.01$) whereas feed to gain ratio was not significantly altered, as compared to the control environment. Within the tropical climate, during the warm season, there was a 9% reduction in the average daily gain in animals between 35 and 90 kg, as compared to the cool season ($P < 0.01$).

Whatever the season, average backfat thickness was lower in the tropical climate than in the control environment ($P < 0.05$). The environmental conditions had no significant effect on muscle percentage, whereas fat percentage of pigs raised in a tropical climate during the warm season was lower than that of animals reared during the cool one ($P < 0.05$, Tab. II).

Between 35 and 90 kg live weight, castrates ate 11% ($P < 0.001$) more food, had a 7% ($P < 0.05$) higher average daily gain and were fatter at slaughter ($P < 0.05$) than females (Tab. II). No interactions between environment and sex were observed in growth performance and carcass traits.

Table II. The effect of the tropical climate and season on performance and carcass traits of ad libitum fed growing pigs in relation to the live weight.

	Environment			Sex			Significance[1]	
	Control	Tropical climate						
	20 °C, 75%RH	Cool season 24.8 ± 3.6 °C	Warm season 27.9 ± 3.0 °C	females	castrates	R.S.D.	E	Sex
Number of pigs	20	10	10	20	20			
Initial weight (kg)	14.6	14.0	14.9	14.2	14.6	1.8	ns	ns
Final weight (kg)	93.2	93.6	94.3	93.4	93.7	2.5	ns	ns
15 to 35 kg period								
Feed intake ($g \cdot d^{-1}$)	1281[a]	1239[ab]	1206[b]	1182	1302	112	*	**
Average daily gain (g)	752	759	757	733	779	60	ns	*
Feed:gain ratio	1.70[a]	1.63[ab]	1.59[b]	1.61	1.66	0.12	**	ns
35 to 90 kg period								
Feed intake ($g \cdot d^{-1}$)	2301[a]	2101[b]	2001[b]	2028	2254	93	***	***
Average daily gain (g)	910[a]	883[a]	802[b]	839	901	64	**	*
Feed:gain ratio	2.53	2.38	2.50	2.42	2.50	0.15	ns	ns
Average backfat (cm)	2.24[a]	2.06[b]	2.05[b]	1.93	2.28	0.14	*	*
Muscle (%)	55.0	54.1	54.2	55.5	53.3	2.0	ns	*
Fat (%)	21.4[ab]	22.6[a]	20.1[b]	20.4	22.9	2.4	*	*

E: effect of environment.
[1] ns: not significant; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.
[a, b] Means that do not have a common superscript letter differ significantly.

3.3. Meat quality, muscle and adipose tissue composition

The present results indicate no significant influence of sex on the chemical composition of adipose tissue and muscle, fatty acid composition of lipids and meat quality. Only pooled data for sex are therefore presented.

3.3.1. Adipose tissue

The lipid content of the entire backfat was lower than that of leaf fat (78.9 ± 0.5% and 83.6 ± 0.8%, respectively, $P < 0.001$) irrespective of the environment, whereas protein content was higher (3.9 ± 0.2% and 2.2 ± 0.2%, respectively, $P < 0.001$). Backfat outer layer was poorer in lipids than the inner layer in the tropical climate (75.6 ± 0.8% and 78.2 ± 0.5%, respectively, $P < 0.05$) whereas the lipid contents of the two layers were similar in the control environment. A reduction in the lipid content of the outer layer of backfat ($P < 0.05$) was observed in the tropical climate during both seasons, as compared to the control environment (Tab. III). Tropical climate not only modified the amount of lipids deposited in backfat but also influenced their fatty acid composition (Tab. IV). The unsaturation coefficient of lipids in backfat in both layers was higher in the tropical climate than in the control environment ($P < 0.01$). However, only polyunsaturated fatty acids (C18:2 and C18:3) were

Table III. The effect of the tropical climate and season on the chemical composition of subcutaneous and leaf adipose tissues in growing pigs slaughtered at 90 kg live weight.

	Environment				
	Control	Tropical climate			Significance[1]
Chemical composition (%)	20 °C, 75%RH	Cool season 24.8 ± 3.6 °C	Warm season 27.9 ± 3.0 °C	R.S.D.	E
Entire backfat					
Dry matter	86.8	88.1	85.9	3.3	ns
Lipid	78.8	78.1	79.9	2.5	ns
Protein	4.1	3.6	3.9	1.1	ns
Backfat outer layer					
Dry matter	88.7	86.6	86.0	1.9	ns
Lipid	80.6[a]	76.0[b]	75.1[b]	2.5	*
Protein	4.0	3.8	3.8	0.5	ns
Backfat inner layer					
Dry matter	88.8	89.4	89.5	1.4	ns
Lipid	78.8	78.2	78.1	1.7	ns
Protein	3.2	3.4	3.4	0.4	ns
Leaf fat					
Dry matter	88.3[b]	92.0[a]	86.9[b]	3.3	*
Lipid	84.6[a]	86.6[a]	79.6[b]	4.0	*
Protein	2.3	1.7	2.6	0.8	ns

E: effect of environment.
[1] ns: not significant; * $P < 0.05$.
[a, b] Means that do not have a common superscript letter differ significantly.

increased in the tropical climate as compared to the control environment ($P < 0.05$), whereas monounsaturated fatty acids (C18:1 and C20:1) were reduced ($P < 0.05$).

In the tropical climate, there was a 5.1 percentage units ($P < 0.05$) decline in the dry matter content of leaf fat and a 7.0 percentage units ($P < 0.05$) decrease in its lipid content

Table IV. The effect of the tropical climate and season on the fatty acid composition of lipids in subcutaneous and leaf adipose tissues (as % total fatty acids) in growing pigs slaughtered at 90 kg live weight.

	Environment				
	Control	Tropical climate			Significance[1]
Fatty acids (%)	20 °C, 75%RH	Cool season 24.8 ± 3.6 °C	Warm season 27.9 ± 3.0 °C	R.S.D.	E
Backfat					
C14:0	1.2	1.3	1.3	0.2	ns
C16:0	24.4	24.4	24.1	0.9	ns
C16:1	2.1	1.9	2.2	0.4	ns
C18:0	12.8	13.4	12.0	1.5	ns
C18:1	41.1[a]	37.3[b]	39.2[ab]	1.9	**
C18:2	16.8[a]	19.9[b]	19.5[b]	2.6	*
C18:3	0.85[a]	1.17[b]	1.02[ab]	0.18	*
C20:0	0.13	0.12	0.22	0.10	ns
C20:1	0.62[a]	0.51[ab]	0.46[b]	0.11	*
∑ monounsaturated	43.8[a]	39.7[b]	41.9[ab]	2.2	**
∑ polyunsaturated	17.7[a]	21.1[b]	20.5[ab]	2.8	*
Unsaturation coefficient[2] (%)	1.30[a]	1.35[b]	1.37[b]	0.04	**
P/S[3]	0.46[a]	0.54[b]	0.55[b]	0.08	*
Leaf fat					
C14:0	1.4	1.4	1.5	0.1	ns
C16:0	28.0	27.8	28.0	1.3	ns
C16:1	1.7	1.7	1.7	0.3	ns
C18:0	19.5	19.2	19.4	1.7	ns
C18:1	34.8	33.5	34.0	2.7	ns
C18:2	13.3	14.9	14.0	3.3	ns
C18:3	0.65[a]	0.90[b]	0.79[ab]	0.18	**
C20:0	0.20	0.17	0.18	0.04	ns
C20:1	0.45	0.43	0.43	0.07	ns
∑ monounsaturated	37.0	35.6	36.1	2.9	ns
∑ polyunsaturated	13.9	15.8	14.7	3.5	ns
Unsaturation coefficient[2] (%)	1.30	1.33	1.31	0.06	ns
P/S[3]	0.30	0.33	0.30	0.08	ns

E: effect of environment.
[1] ns: not significant; * $P < 0.05$; ** $P < 0.01$.
[a, b] Means that do not have a common superscript letter differ significantly.
[2] The unsaturation coefficient (UC) was calculated as follows:
UC = ((%C16:1 + %C18:1)*1 + (%C18:2*2) + (C18:3*3))/(C16:1 + C18:1 + C18:2 + C18:3).
[3] $\text{P/S} = \frac{\sum \text{polyunsaturated fatty acids}}{\sum \text{saturated fatty acids}}$.

during the warm season, as compared to the cool period of the year (Tab. III). The environment had very little influence on the fatty acid composition of the lipids in leaf fat (Tab. IV).

3.3.2. Meat quality criteria

pH1 in the muscles was not significantly influenced by the environment (Tab. V). pH2 in M. *longissimus dorsi* ($P < 0.01$) and M. *biceps femoris* ($P < 0.05$) was higher during the warm season in the tropical climate than in the control environment whereas no difference was observed in M. *semispinalis*. Exposure of the pigs to the tropical climate conditions induced a decrease in moisture loss of *biceps femoris* and *semispinalis* muscles ($P < 0.05$), as compared to the control environment (Tab. V).

Table V. The effect of tropical climate and season on meat quality and chemical composition of M. *longissimus dorsi* and M. *semispinalis* in growing pigs slaughtered at 90 kg live weight.

	Environment				
	Control	Tropical climate			Significance[1]
	20 °C, 75%RH	Cool season 24.8 ± 3.6 °C	Warm season 27.9 ± 3.0 °C	R.S.D.	E
Meat quality					
M. *longissimus dorsi*					
pH1	6.21	6.21	6.37	0.20	ns
pH2	5.52[a]	5.60[ab]	5.71[b]	0.08	**
Moisture loss (%)[2]	21.4	21.4	20.7	2.8	ns
M. *biceps femoris*					
pH1	6.05	6.06	6.17	0.20	ns
pH2	5.58[a]	5.63[ab]	5.88[b]	0.08	*
Moisture loss (%)	24.8[a]	22.7[ab]	21.4[b]	3.2	*
M. *semispinalis*					
pH1	6.08	6.11	6.10	0.21	ns
pH2	5.84	5.86	5.83	0.15	ns
Moisture loss (%)	18.5[a]	15.3[b]	15.5[b]	1.9	*
Chemical composition (%)					
M. *longissimus dorsi*					
Dry matter	25.8	26.2	25.1	1.6	ns
Lipid	1.8	1.9	1.9	0.4	ns
Protein	22.4	23.0	22.6	1.4	ns
M. *semispinalis*					
Dry matter	25.4[ab]	27.4[a]	23.1[b]	2.4	*
Lipid	5.9[ab]	6.7[a]	4.6[b]	1.4	*
Protein	18.2[a]	19.4[b]	16.0[c]	1.1	***

E: effect of environment.
[1] ns: not significant; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.
[a, b, c] Means that do not have a common superscript letter differ significantly.
pH1: pH 45 min post mortem; pH2: pH 24 h post mortem.
[2] Moisture loss was calculated as the weight of water lost in filter paper divided by the initial weight of fresh muscle samples and expressed as a percentage.

3.3.3. Muscle

The lipid content of M. *semispinalis* was about three times higher than that of M. *longissimus dorsi*, averaging 5.7 ± 1.4 and 1.9 ± 0.1%, respectively ($P < 0.001$). The dry matter, protein and lipid contents of M. *longissimus dorsi* was not altered by the environmental conditions (Tab. V). However, the environment had a mild influence on the fatty acid composition of lipids in M. *longissimus dorsi* (Tab. VI). In the

Table VI. The effect of the tropical climate and season on fatty acid composition of lipids in M. *longissimus dorsi* and M. *semispinalis* (as % total fatty acids) in growing pigs slaughtered at 90 kg live weight.

	Environment				
	Control	Tropical climate			Significance[1]
Fatty acids (%)	20 °C, 75%RH	Cool season 24.8 ± 3.6 °C	Warm season 27.9 ± 3.0 °C	R.S.D.	E
M. *longissimus dorsi*					
C14:0	1.4	1.6	1.3	0.4	ns
C16:0	24.8	25.1	24.3	1.1	ns
C16:1	2.8[a]	2.7[a]	3.2[b]	0.4	*
C18:0	12.9[ab]	13.4[a]	12.3[b]	0.6	*
C18:1	41.7[ab]	40.0[a]	43.2[b]	1.5	**
C18:2	13.1	13.6	12.1	1.8	ns
C18:3	0.34	0.33	0.29	0.11	ns
C20:0	0.10	0.10	0.15	0.05	ns
C20:1	0.46	0.47	0.66	0.19	ns
C20:4	2.4	2.7	2.5	0.9	ns
∑ monounsaturated	44.9[a]	43.1[a]	47.1[b]	1.6	**
∑ polyunsaturated	15.8	16.6	14.9	2.1	ns
Unsaturation coefficient[2] (%)	1.24	1.25	1.22	0.04	ns
P/S[3]	0.41	0.42	0.39	0.06	ns
M. *semispinalis*					
C14:0	1.3	1.4	1.4	0.1	ns
C16:0	25.3	25.5	25.8	0.8	ns
C16:1	2.4a	2.3[a]	2.8[b]	0.2	*
C18:0	14.8	15.4	14.3	1.0	ns
C18:1	42.7[a]	41.8[a]	45.0[b]	1.4	*
C18:2	11.5[a]	11.5[a]	9.1[b]	1.2	*
C18:3	0.48[a]	0.50[a]	0.37[b]	0.05	*
C20:0	0.13	0.12	0.11	0.02	ns
C20:1	0.56	0.57	0.50	0.06	ns
C20:4	0.83[a]	0.91[a]	0.62[b]	0.16	*
∑ monounsaturated	45.7[a]	44.7[a]	48.3[b]	1.5	*
∑ polyunsaturated	12.8[a]	12.9[a]	10.1[b]	1.4	*
Unsaturation coefficient[2] (%)	1.22[a]	1.22[a]	1.17[b]	0.02	*
P/S[3]	0.31[a]	0.30[a]	0.24[b]	0.04	*

E: effect of environment.
[1] ns: not significant; * $P < 0.05$; ** $P < 0.01$.
[a, b] Means that do not have a common superscript letter differ significantly.
[2, 3] Unsaturation coefficient and P/S were calculated as indicated in Table IV.

tropical climate, a rise in the percentage of C16:1 ($P < 0.05$) and C18:1 ($P < 0.01$) during the warm season was observed relative to the cool season, but it did not result in a significant change in the unsaturation coefficient.

Contrary to M. *longissimus dorsi*, the chemical composition of M. *semispinalis* was widely modified by the season in the tropical climate. Under the tropical climate, the dry matter content of M. *semispinalis* was 4.3 percentage units lower ($P < 0.05$) during the warm season than that observed during the cool season, as well as there being a decline in the protein ($P < 0.001$) and lipid ($P < 0.05$) contents (Tab. V). There was a concomitant increase in the proportion of monounsaturated fatty acids (C16:1 and C18:1) ($P < 0.05$) whereas polyunsaturated fatty acids (C18:2 and C18:3) ($P < 0.05$) were reduced (Tab. VI). In M. *semispinalis*, the polyunsaturated to saturated fatty acids ratio ($P < 0.05$) and the unsaturation coefficient ($P < 0.05$) were the lowest in the tropical climate during the warm season.

4. DISCUSSION

The comparison between the ambient temperatures observed during this trial and those recorded over 20 successive years using a weather station, showed that experimental conditions were representative of a tropical climate in the area. This climate is characterised by a high RH, an average ambient temperature changing from about 24 to 28 °C from one season to another and marked nocturnal variations in these two climatic components. The present results indicate that the changes in growth performance due to exposure to a tropical climate are concomitant to modifications in adipose tissue and muscle, but are not exactly the same as the variations due to constant high ambient temperature [18]. This can be related to the complexity of the tropical climate which does not quite mimic the effects of average ambient temperature probably due to the rather large nocturnal fluctuation in ambient temperature.

4.1. Growth performance and carcass characteristics

The reduced VFI in the tropical climate during the warm season is in good agreement with the well known negative relation between ambient temperature and VFI [24, 28]. When pigs are reared in semi-open-air conditions in temperate areas, an 8% decline in average daily gain has been shown in 35 to 90 kg animals during the summer as compared to the winter [21, 33]. This finding agrees with present data indicating a similar 9% reduction in growth rate during the warm season in the tropics, as compared to the cool one. It is well known that in pigs fed ad libitum, the increase in ambient temperature induces a reduction in carcass fatness [17, 23, 25, 31], when the animals are given a protein balanced diet [19, 32]. These findings are consistent with present data obtained in the tropical climate showing a reduction in backfat thickness whatever the season and the lowest fat percentage during the warm season.

4.2. Adipose tissue composition

In the tropical climate, the variation between the lipid contents of the two layers of backfat was likely due to the difference in the lipid metabolism of those layers, as previously reported in the study of Camara et al. [5]. This study shows that the outer layer of backfat is richer in lipids in 20 to 50 kg Large White pigs whereas it is poorer in heavier animals, the shift occurring at about 100 kg live weight. Our present results demonstrate that the exposure of pigs to tropical conditions modifies both the lipid content and the concentration in various fatty acids of the subcutaneous fat whereas only the lipid and linolenic contents of leaf fat are altered. Such differences in tissue susceptibilities to the environment have

previously been reported [18] and could be related to the actual temperature of the tissue [20].

The shift of fat distribution from external sites towards internal sites previously found during the warm season in tropical climates [29], is connected to a reduction in both the weight of backfat and in the lipid content of its outer layer. Similar changes have also been recorded at a constant high ambient temperature of 31.5 °C in 30 kg pigs [28]. The reduction in feed intake has previously been described to induce a lower weight and lipid content of backfat [1, 37]. However, according to Lebret et al. [16], the modifications in the chemical composition of backfat with changes in temperature and season are not necessarily related to the concomitant variations in VFI. The shift in body fat distribution was therefore assumed to reflect an adaptation to warm conditions since heat loss is promoted through reduced thermal insulation [15]. Further investigations are still needed to describe the mechanisms by which ambient temperature alters body fat distribution.

Irrespective of the influence of the environment, the level of C18:2 in backfat was much higher than the recommended 12–15% [36]. The high level of C18:2 in backfat was likely due to feed composition, since it is well known that linoleic acid concentration in carcass fat is highly correlated to that contained in the diet [7, 38]. In the present trial, the two diets given to the pigs contained respectively 18.5 and 19.9 g C18:2·kg^{-1}, whereas the recommended level is about 10 to 12 g·kg^{-1}. The decrease in C18:1 and C20:1 together with the increase in C18:2 and C18:3 in the backfat of pigs reared in the tropical climate have previously been shown at a constant high temperature of 28 °C [18]. The reduced VFI in the tropical climate accounts for the increase in C18:2 and C18:3 in backfat, since the negative correlation between the level of feed intake and the C18:2 and C18:3 contents of fat has been well described [37, 38]. The higher unsaturation coefficient of external fat in warm conditions in the tropical climate, is consistent with the findings of Lebret et al. [16]. The latter have shown that, in temperate areas, the degree of unsaturation of backfat is higher in animals fed ad libitum during the summer at an average temperature of 26 °C than in those raised during the winter at an average temperature of 18.3 °C. This is considered as favourable, as far as the nutritional value is concerned. However, Lebret et al. [16] indicated that the summer has positive effets not only on the higher unsaturation of subcutaneous adipose tissue but also on its increased degree of firmness, in relation to higher levels of C16:0 and C18:0. In the present trial, the C16:0 and C18:0 contents in backfat were not modified by the environment suggesting that backfat firmness did not change. However, further investigations are needed to evaluate the effects of warm and humid conditions on the actual backfat firmness and therefore its ability to be processed.

4.3. Muscle composition and lean meat quality

The higher lipid content of red skeletal muscle, such as M. *semispinalis*, compared to white muscle, such as M. *longissimus dorsi*, is well documented [4]. The current finding of a decrease in the lipid content of M. *semispinalis* during the warm season in the tropical climate whereas M. *longissimus dorsi* is not affected, is consistent with previous reports. Environmental temperature has been shown to modify chemical composition, fibre types and metabolic activities in red muscle while no or a minor change has been observed in white muscle [18, 27].

It is known that polyunsaturated to saturated fatty acids ratio is one of the most reliable markers of nutritional value of lean meat [38]. The average values of the polyunsaturated to saturated fatty acids ratio are close to the recommended 0.45 value in M. *longissimus*

dorsi and lower in M. *semispinalis*. In the present study, environmental conditions had no effect on the polyunsaturated to satured fatty acids ratio in M. *longissimus dorsi*. Similar results were observed by Gandemer et al. [13] when comparing pigs raised indoors or outdoors.

Since the average ambient temperature in tropical climate is higher than in the control environment, higher values of pH2 are measured in the *longissimus dorsi* and *biceps femoris* muscles. Previous studies on the effect of ambient temperature on pH2 are controversial. Lefaucheur et al. [18] described an increase in pH2 in the *longissimus dorsi* muscle at a constant ambient temperature of 28 °C as compared to 12 °C which is in good agreement with the present data. However, in temperate areas, Lebret et al. [16] found no change in pH2 in the summer at an average temperature of 26 °C as compared to the winter at an average 18.3 °C. The higher values of pH2 in the tropical climate are not closely related to moisture loss, as previously reported [18].

Altogether, the results of this study suggest that the changes in tissue composition and pork quality induced by a tropical climate may be favourable. The higher ultimate pH and the lower moisture loss found during the warm season may reflect the improvement in the technological quality of lean meat. The reduced lipid content of the outer layer of backfat and the higher degree of unsaturation of entire backfat might suggest a better nutritional quality of fat. However, the chemical composition of M. *longissimus dorsi* hardly changed. The suggested favourable influence of high temperature in the tropical climate on meat quality had previously been demonstrated at a constant 28 °C [18]. This should be confirmed by further information. However, in the tropics, the consumers' preference for locally produced pork, as compared to imported meat, might also be due to the use of local breeds. In the Caribbean, better technological and sensory qualities of meat have been suggested in local Creole pigs compared to Large White animals [9] but this still has to be clearly demonstrated. We thus plan to study the interactive effects of climate and breed, i.e. Large White vs. Creole, on meat properties and tissue composition in the tropics.

ACKNOWLEDGMENTS

The authors gratefully acknowledge G. Gravillon and A. Cléonis for high skills in carrying out the experiment as well as P. Marival, J. Belfort, A. Bructer, A. André, B. Calif, D. Feuillet and L. Philibert for technical assistance in the slaughtering of pigs and chemical analyses. Particular thanks are owed to A. Mounier for performing fatty acid composition of lipids and for his precious advice in lipid analyses.

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