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CAPÍTOL 3

A comparison of halothane homozygous negative and positive Pietrain sire lines in relation to carcass and meat quality and welfare traits

ABSTRACT

Barrows (n=164) and gilts (n=249) from crosses of a Pietrain homozygous halothane recessive (Pi nn) and two Pietrain homozygous dominant (Pi NN-a and Pi NN-b) sire lines with Landrace×Large NN sows, were used to study the effect of terminal sire and pre-slaughter treatment on meat quality and animal welfare. The pigs from each of the two farms where they were finished were delivered to the abattoir in two batches differing in the pre-slaughter conditions. A total of 90 pigs (54 NN and 36 Nn) were assigned to a long pre-slaughter treatment (6 h transport and 14.5 h lairage) and 89 (57 NN and 33 Nn) to a short pre-slaughter treatment (4.5 h transport and 2.5 h lairage) in Farm 1, and 118 (65 NN and 53 Nn) to the long (7 h transport and 14 h lairage) and 114 (66 NN and 48 Nn) to the short pre-slaughter treatment (1.5 h transport and 2 h lairage) in Farm 2. In Farm 1, heart rate was recorded throughout loading and transport and blood samples were collected before loading and after transport to measure cortisol, creatine phosphokinase (CPK) and lactate dehydrogenase (LDH). Carcasses were classified and commercial cutting was carried out. At 24 h, meat quality was assessed on the *Longissimus thoracis* muscle by measuring electrical conductivity (PQM), colour (Minolta CR 200 and Japanese scale), pHu and drip losses. Halothane carriers showed a higher mean heart rate and higher increase in CPK levels ($P<0.05$) after transport in the short pre-slaughter treatment than halothane free pigs. No effect was observed in cortisol or LDH values. Pi NN-a sired pigs had a higher live and carcass weight ($P<0.001$) and loin depth ($P<0.05$), but lower killing out percentage ($P<0.01$) and leg yield ($P<0.01$) compared with the progeny of the other two terminal sires. Gilts were leaner ($P<0.001$), had a higher killing out percentage ($P<0.001$) and higher yields of primal cuts ($P<0.001$) compared with barrows. Pi nn sired pigs had poorer meat quality (higher PQM values in both farms, $P<0.01$) than Pi NN-a sired pigs. Long pre-slaughter treatment resulted in darker meat ($P<0.01$) in both farms and in higher pHu ($P<0.001$) in Farm 1 than short pre-slaughter treatment. Conversely, pigs subjected to the short pre-slaughter treatment showed higher PQM values ($P<0.01$) in Farm 1 and higher PSE percentage ($P<0.05$) in both farms compared with the ones subjected to the long pre-slaughter treatment. These results suggest that Pietrain halothane

free sire lines could produce similar results on carcass quality to halothane carriers, without compromising meat quality and welfare.

***Keywords**:* pigs, halothane gene, meat quality, animal welfare, pre-slaughter treatment.

INTRODUCTION

The halothane gene (n) has been demonstrated to be the main cause of pale, soft and exudative (PSE) pigmeat in pigs subjected to an acute stressful situation before slaughter (Cassens, et al., 1975). Moreover, stressful conditions such as transportation can trigger the onset of malignant hyperthermia (MH), especially in homozygous recessive (nn) pigs, which may ultimately lead to death or to the development of PSE meat (Barton-Gade et al., 1988; McPhee et al., 1994; Murray and Johnson, 1998). Both higher mortality rates and PSE incidence result in important economic losses and present welfare implications. Commercially, the gene has been of interest since it is associated with a higher carcass lean content and better conformation in nn pigs compared with pigs free of this mutation (NN) (Webb and Simpson, 1986; Leach et al., 1996). When the DNA genetic probe for the halothane gene was commercially available after the findings of Fujii et al. (1991), the debate was focused on whether to use halothane carrier boars (Nn), achieved from crosses of Pietrain nn with Large White NN, or to select halothane free lines, mainly from Pietrain sire lines. The first alternative was based on the idea that Nn slaughter pigs could cope with pre-slaughter stress like NN pigs, according to their performance when subjected to the halothane challenge test. However, recent studies have reported that pre-slaughter deaths are also higher among Nn individuals compared with NN (Murray and Johnson, 1998). Moreover, even though some investigations indicate that carriers do have certain advantages in terms of carcass quality such as greater carcass yield and lean content compared with halothane free pigs (Leach et al., 1996; Larzul et al., 1997; Fisher et al., 2000), other works have found little effect of the n allele on carcass traits (McPhee and Trout, 1995; García-Macías et al., 1996). Thus, the second alternative of selecting halothane free boar lines has been considered on commercial grounds and has given rise to new lines of investigation.

The halothane gene as well may be linked to impoverished individual welfare, since the assumption that the mutation is associated with a genetic susceptibility to stress underlies

most of the scientific literature on the gene. Physiological and behavioural responses to situations such as transport and lairage can be used to assess the amount of effort animals must make to cope with the associated stresses (Warriss et al., 1998a). The effect of the halothane gene on physiology and behaviour has been investigated less than the aspects related to meat and carcass quality and the results have been somewhat contradictory. However, some investigations have found nn, and to a lesser extent Nn, pigs to have an unusually responsive sympatho-adrenomedullary system, being more prone to catecholamine overloading and higher heart rates (Gregory and Wotton, 1981; Geers et al., 1994) and present higher cortisol (Marple and Cassens, 1973; Fàbrega et al., 2001) or creatin phospokinase increases (Honkavaara, 1988; Rundgren et al., 1990; Gispert et al., 2000) after certain stressful circumstances like pre-slaughter practices. The welfare of these individuals could therefore be compromised. In this regard, consumer attitudes to animal welfare have been changing over the last decades, and their demand for a certain welfare guarantee may have an influence on market positioning in the future.

To overcome the genetic antagonism between carcass leanness and meat quality traits and welfare (Cassens et al., 1975; Sellier and Monin, 1994), new approaches have become available to producers with the selection of improved Pietrain NN terminal boar lines. Hence, these new lines could bring the benefits of the breed in terms of carcass leanness and primal cut yield, without the disadvantages of PSE meat, high mortality rates and welfare drawbacks.

The aim of this study was to investigate the effect of three Pietrain terminal sires different with respect to halothane status (NN or nn) on carcass and meat quality traits and welfare of pigs subjected to two different pre-slaughter treatments.

MATERIAL AND METHODS

Animals

The 413 pigs (249 gilts and 164 barrows) used in this experiment were crosses of Landrace×Large White homozygous dominant sows (NN) with three Pietrain boar lines with different halothane genotype, a Pietrain nn (Pi nn) and two Pietrain NN (Pi NN-a and Pi NN-b). The two halothane free Pietrain lines came from a different genetic company and were produced for the purpose of reducing the meat quality problems associated with

the halothane gene whilst maintaining Pietrain carcass standards. Eight boars of each line were used for the inseminations which were carried out within a week. Piglets were weaned at 21 days of age. The offspring of Pi nn (n=169) were heterozygous (Nn) and the offspring of the other two terminal sires were all NN (n=107 Pi NN-a sired pigs and n=135 Pi NN-b sired pigs). The boars used and a random sample of 30 piglets were tested to assure the halothane genotype using PCR amplification and digestion with restriction enzymes as described by Fujii et al. (1991). (The HAL-1843 trademark is licensed from Innovations Foundation, Toronto, Canada). After staying in a weaned unit for 6 weeks, the pigs were moved to two finishing farms (Farm 1 and Farm 2). In both farms, pigs were kept in groups of 10-12 animals and fed *ad libitum* on the same diet. All the pigs were weighed four days before slaughter using the Allflex FX11[â] electronic weighing system.

Pre-slaughter conditions

The experiment was carried out in July 2000. All the pigs of each farm were slaughtered the same day, Farm 1 in the third week of July and Farm 2 the last week of July. Two different pre-slaughter treatments (long and short) were defined for each farm according to the length of the transport and the lairage times. These transport and lairage times were chosen to resemble extreme commercial conditions, since in the Spanish pig industry a wide variation in transport, lairage and fasting times exists (Gispert et al., 2000). Therefore, short treatments consisted of the shortest transportation time from the farm of origin to the abattoir combined with a minimal recommended lairage time of 2 h (Warriss et al., 1998b), whereas long treatments were meant to consist of a longer journey (6-7 h) combined with a long off feed lairage time (10 h). Due to practical constraints, the lairage time of the long treatments surpassed in 4 hours the planned original time. Taking into account this consideration, the final treatments were the following ones (as summarised in Table 1). For Farm 1, the duration of the transport was 6 and 4.5 h, and duration of lairage was 14.5 and 2.5 h, for the long and short conditions, respectively. For Farm 2, duration of the transport was 7 and 1.5 h and lairage time was 14 and 2 h, for the long and short conditions, respectively. In both pre-slaughter treatments the animals were slaughtered together at 12:00. The pigs subjected to the long pre-slaughter conditions were loaded the day before slaughter from 14:30 to 15:30 in Farm 1 and from 14:00 to 15:00 in Farm 2 and unloaded at the abattoir at 21:30 and 22:00, respectively. In the short pre-slaughter

treatment, the pigs were loaded the day of slaughter from 04:00 to 05.00 in Farm 1 and from 07:30-08:30 in Farm 2 and unloaded at the abattoir at 09:30 and 10:00, respectively. In Farm 1, a total of 90 animals were delivered in the long pre-slaughter treatment distributed in 54 NN (19 Pi NN-a sired and 35 Pi NN-b sired pigs) and 36 Nn and 89 animals were delivered in the short pre-slaughter treatment, distributed in 56 NN (20 Pi NN-a sired and 36 Pi NN-b sired pigs) and 33 Nn. In Farm 2, a total of 118 animals were delivered in the long pre-slaughter treatment, distributed in 65 NN (34 Pi NN-a sired and 31 Pi NN-b sired pigs) and 53 Nn. In the short pre-slaughter treatment, 114 animals were delivered distributed in 66 NN (34 Pi NN-a sired and 32 Pi NN-b) and 48 Nn. The average outdoor temperature during transport and unloading in Farm 1 ranged from 27 to 31 ºC and from 15 to 18 ºC for the long and short pre-slaughter treatments, and in Farm 2 from 25 to 30 ºC and from 15 to 18 ºC, respectively.

Table 1. Pre-slaughter treatments for the two farms

	Pre-slaughter conditions			
	Farm 1		Farm 2	
	Long	Short	Long	Short
Loading time	14:30-15:30	04:00-05:00	14:00-15:00	07:30-08:30
Unloading time	21:30	09:30	22:00	10:00
Slaughter time	12:00	12:00	12:00	12:00
Transport length (h)	6	4.5	7	1.5
Lairage length (h)	14.5	2.5	14	2
On-farm feed withdrawal (h)	12	12	12	12
Total feed withdrawal (h)	31.5	18	33	15.5
Outdoor temperature (ºC)	27-31	15-18	25-30	15-18
Total number of pigs	90	89	118	114
Terminal sire distribution				
Pi nn	36	33	53	48
Pi NN-a	19	20	34	34
Pi NN-b	35	36	31	32

All pigs were subjected to the same on-farm fasting time (12 h) and also the stocking density during transport was the same (0.5 m^2/100 kg pig). The same lorry was used for the long and short pre-slaughter treatment in both farms, but with a different driver. The lorry was a rigid truck with three decks divided in eight compartments each deck and equipped with natural ventilation and hydraulic lifts for loading and unloading. No electric goads were used. Mixing of unfamiliar animals was avoided during transport, but it was not possible at lairage. Stocking density at lairage was 0.45 m^2/100 kg pig, in pens of 70-80 individuals. The animals were showered during transport for 5-10 s each half hour as long as the temperature exceeded 20 ºC and at lairage for 10 m at the arrival and for 10 m prior sacrifice. Drinking water was available during transport and at lairage. The abattoir selected used a CO_2 stunning system with a maximum atmosphere concentration of CO_2 of 85% on the bottom position of the well and a mean CO_2 cycle of 120 s. The line speed was 600 pigs/h.

Physiological measurements

Physiological measurements were taken in Farm 1, in 10 gilts (3 Pi NN-a, 2 Pi NN-b and 5 Pi nn sired) for each pre-slaughter treatment. Heart rate and blood indices of stress such as cortisol, creatine phosphokinase (CPK) and lactate dehydrogenase (LDH) were recorded. These gilts were transported in the same lorries as the rest of the animals, but placed individually to prevent damage to the heart rate monitors, dividing each of five compartments of the upper tier in two.

Measurements of heart rate were taken using the Polar system (Polar Vantage NV, Polar Electro, Oy, Finland). This heart rate monitor is composed of a chest band inside which are the conductive electrodes, a sensor/transmitter connected to the chest strap and a wrist monitor storing the information which is later transferred to an electronic reading device. The electrode belt with built-in transmitter was fitted around the thorax of the pig caudal to the forelimbs. The receiver was protected, positioned on the belt on the dorsal midline. Medical tape (Omniplast™, Hatmann) was fitted around the belt and receiver for protection. The devices were attached to the pigs 2 h before they were loaded, but for the statistical analysis only the 30 min corresponding to loading were considered. The frequency of heart beats was measured every minute. The arithmetic mean of heart rate values was calculated for every 5 min period. Four gilts in each pre-slaughter treatment

were discarded because their recordings contained more than 60% missing data. Therefore, the analysis has been performed for 3 NN pigs and 3 Nn by pre-slaughter treatment. Heart rate devices were removed on the lorry when the animals arrived at the slaughterhouse.

Two blood samples were collected from each individual. The first one was taken before loading, when the animals were restrained prior to attaching the heart rate devices. This sample was considered the basal index of each pig, taking care that the sample was collected within 2-3 min before the beginning of the blood sampling procedure to avoid major influences of the sampling procedure itself (Broom and Johnson, 1993). The second sample was collected without restraining on the lorry just after the arrival at the abattoir. Samples were collected from the jugular vein using 10 ml sodium heparin-coated evacuated tubes (Vacutainer™). Immediately after blood collection tubes were stored in a cooler at 5-10 ºC. Within 30 min blood samples were centrifuged (15 min at 3500 rpm). Plasma obtained was put into cryotubes of 1 ml and frozen and stored at –20 ºC pending analysis. Cortisol concentrations were determined by competitive enzyme immunoassay (Cortisol ELISA, DRG Diagnostics, EIA-1887) and expressed in ng/ml. Each sample was analysed twice to determine cortisol concentration and the average between both determinations was used for statistical analysis. CPK and LDH were assessed by enzyme kits (COBAS MIRA) at 37 ºC, by standard methods recommended by the International Federation of Clinical Chemistry (IFCC). The results were expressed in UI/l.

Measurements of carcass and meat quality

The carcass weight and its estimated lean content using the Fat-o-Meater grading probe (Gispert and Diestre, 1994) were recorded for each carcass before the chilling process. The carcasses were chilled in a chilling tunnel for 1 h and 45 min at -7, -3 and 1 ºC and after kept in conventional chilling rooms at 1-3 ºC for 2 h. The left carcass was commercially cut and the leg and loin of each left carcass were weighed at 4 h post-mortem.

The trimmed loins were kept in refrigeration (3-4 ºC) for 24 h and re-weighed to determine drip losses. Meat quality was assessed by measuring pH in the *Longissimus thoracis* muscle (LT) at 24 h using a hand held Crison micro pH 2001 meter, with a xerolite electrode. The pH meter and electrode were calibrated in pH 4 and pH 7 buffers and re-calibrated after every 20 readings. At 24 h, electrical conductivity with the Pork Quality Meter (PQM-I-INTEK, Gmbh, Germany) was measured as well and the colour of

the loins in the transversal cut at the level of the last rib was evaluated using the Japanese scale (1-5) and the Commission Internationale de l'Éclairage (1976) (CIE) values (L^*, a^* and b^*) with the Minolta CR200. Loins showing PQM values >6 and L^* values >53 were classified as PSE, whereas the loins presenting pHu values >6.00 were classified as Dark, Firm and Dry (DFD).

Statistical analysis

The data were analysed statistically by the Statistical Analysis System (SAS system for windows, v.8.1, 1999-2000). Differences between the variables were accepted as being significant if the probability of rejection of H_0 was less than 5% ($P<0.05$).

The effects of farm, terminal sire and sex on carcass quality traits were analysed by least-square procedures, using the General Linear Models. Since the farm factor did not have a significant effect on carcass traits, the data from both farms were pooled together for the analysis of carcass related parameters. The following model was fitted for main effects (terminal boar and sex) as well as their interactions, using the carcass weight as a covariate:

$$Y_{ijk} = \mu + S_i + T_j + ST_{ij} + bW_{ijk} + e_{ijk}$$

Where Y_{ijk}=the dependent variable; μ=the overall mean; S_i=the ith sex effect (i=barrows or gilts); T_j=the jth terminal sire effect (j=Pi nn, Pi NN-a, Pi NN-b); ST_{ij}=the interaction between sex and terminal sire; bW_{ijk}=the carcass weight; e_{ijk}=the residual error.

For each farm, the following model to analyse the effect of terminal sire, sex and pre-slaughter treatment on meat quality traits was fitted:

$$Y_{ijk} = \mu + T_i + S_j + P_k + TS_{ij} + TP_{ik} + SP_{jk} + e_{ijk}$$

Where Y_{ijk}=is the dependent variable; μ=the overall mean; T_i=the ith terminal sire effect (i=Pi nn, Pi NN-a, Pi NN-b); S_j=the jth sex effect (j=barrows or gilts); P_k=the kth pre-slaughter treatment effect (K=short or long); TS_{ij}=the interaction between terminal sire and

sex; TP_{ik}=the interaction between terminal sire and pre-slaughter treatment; SP_{jk}=the interaction between sex and pre-slaughter treatment; e_{ijk}=the residual error.

All models were reduced to main effects only, because none of the interaction terms in the analysis of variance was significant.

A Chi Square test was applied to compare the distribution of the frequencies of PSE carcasses, according to the halothane genotype or pre-slaughter treatment. Following the classification criteria described previously, only 4 carcasses were classified as DFD in both farms. Therefore, Chi Square could not be performed in this case.

Physiological measurements were analysed according to the halothane genotype of the gilts and not their terminal sire line, since a preliminary analysis showed no difference between Pi NN-a and Pi NN-b gilts. Both genotypes (NN and Nn) were only compared within each pre-slaughter treatment, because of the different individual and environmental conditions or circadian rhythms which could have affected the results. The effect of halothane genotype on heart rate was analysed by the PROC MIXED procedure with the means of heart rate every five min as a repeated measure. The model was fitted for the autoregressive (1) (AR (1)) structure. Genotype, time and their interaction were included in the model as main effects. The analysis was carried out for the whole period of loading and transport, and, also, for the 30 min corresponding to the loading procedure and the lorry period separately.

In a preliminary statistical analysis, differences in the absolute starting levels (sample 1) of cortisol, LDH and CPK between genotypes were analysed by means of a T-test. No significant differences were observed. Therefore, cortisol, LDH and CPK were analysed estimating the ratio between the value obtained in the sample after transport and the sample before transport considered a baseline level. The comparison of ratios instead of absolute levels was chosen to minimize the effect of potential individual differences in the absolute starting levels. The increase ratios obtained of NN and Nn individuals were compared using a Student's t-test.

RESULTS

Physiological measurements

A comparison of the means and standard errors of cortisol, LDH and CPK absolute starting levels and increase after transport from the two halothane genotypes within each pre-slaughter treatment in Farm 1 is presented in Table 2. Halothane genotype only significantly affected CPK increase after transport in the short pre-slaughter treatment, Nn pigs showing a higher increase compared with NN ($P<0.05$).

Table 2. Means (S.E.) of cortisol, LDH and CPK absolute starting levels and increase after transport for the different halothane genotypes compared within pre-slaughter treatments

		Short pre-slaughter treatment			Long pre-slaughter treatment		
		Halothane genotype			Halothane genotype		
Blood index	Variable[1]	NN	Nn	*P*	NN	Nn	*P*
Cortisol	ASL (ng/ml)	127.8 (32.64)	107.1 (14.26)	NS	44.5 (11.24)	42.5 (15.52)	NS
	Ratio	0.8 (0.61)	0.6 (0.11)	NS	2.3 (1.50)	2.7 (1.09)	NS
LDH	ASL (UI/l)	2011.6 (511.03)	1181.8 (174.99)	NS	1542.8 (182.19)	1699.2 (397.79)	NS
	Ratio	1.9 (0.61)	3.2 (0.56)	NS	1.5 (0.18)	1.3 (0.17)	NS
CPK	ASL (UI/l)	3859.3 (1352.53)	1724.7 (243.3)	NS	5165.6 (1931.9)	2663.8 (599.94)	NS
	Ratio	1.9 (1.03)	5.9 (1.16)	*	2.0 (1.41)	3.1 (1.03)	NS

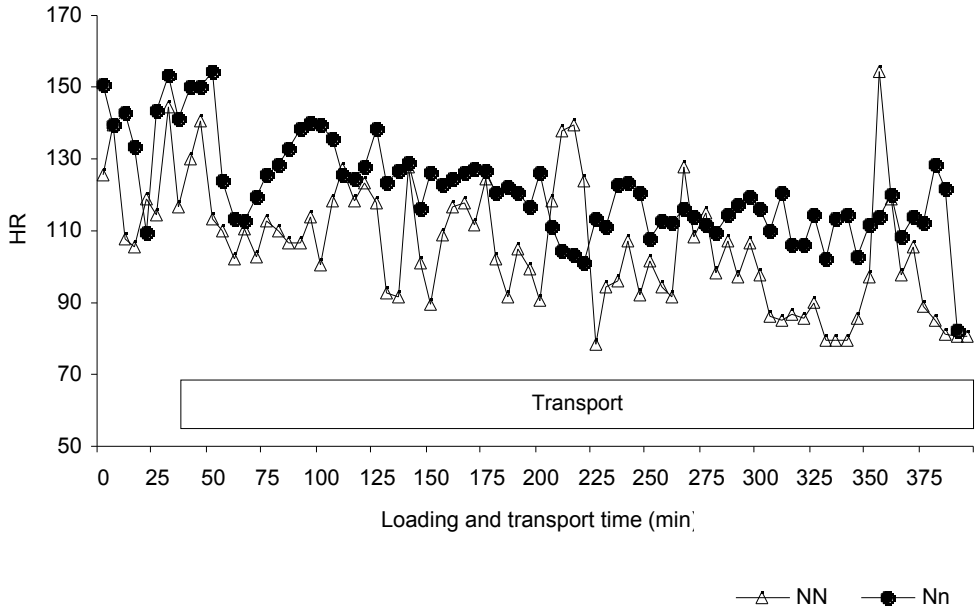
[1] *AST=Absolute Starting Level; Ratio= Sample 2/ Sample 1; * P<0.05*

The evolution of heart rate of both genotypes (NN and Nn) in the long and short pre-slaughter treatment is shown in Figure 1 (a and b, respectively). Mean heart rates during the short pre-slaughter treatment were 104.4 (S.E.=2.32) and 116.7 (S.E.=1.77) and during the long pre-slaughter treatment 105.2 (S.E.=9.28) and 122.1 (S.E.=7.59), for NN and Nn pigs, respectively. The halothane genotype and time had a significant effect on heart rate during transport and during transport and loading combined in the short pre-slaughter

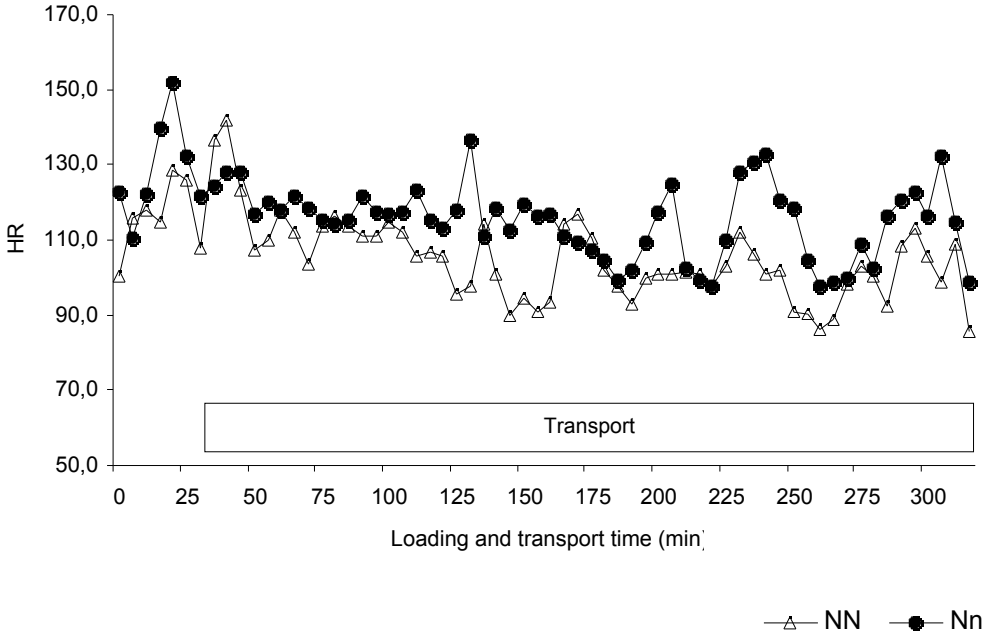
treatment, being higher for Nn gilts compared with NN (P<0.05) and heart rate tending to decrease throughout time.

Figure 1. Means of heart rate during loading and transport of the two halothane genotypes in the long treatment (a) and short treatment (b)

a)



b)



Carcass and meat quality

Least square means and standard errors of carcass quality traits of the terminal sires and sexes are shown in Table 3. There was a significant effect of sex on all the parameters of carcass quality. Gilts had significantly lower live and carcass weights ($P<0.01$), but their killing out ($P<0.001$) and estimated lean content ($P<0.001$) were higher compared with barrows. Loin and leg yields were significantly higher ($P<0.001$) in the gilts as well.

Table 3. Least Square Means and standard errors of carcass quality traits of the different terminal sires and sexes

	Terminal sire				Sex		
	Pi nn	Pi NN-a	Pi NN-b	*P*	Gilts	Barrows	*P*
N	170	106	135		247	164	
Live weight (kg)	104.7 [a] (0.87)	108.5 [b] (1.09)	100.7 [c] (0.97)	***	102.5 (0.72)	106.8 (0.88)	***
Carcass weight (kg)	79.1 [a] (0.72)	81.6 [b] (0.91)	75.7 [c] (0.81)	***	77.4 (0.59)	80.2 (0.73)	**
Killing out (g/kg)	752.5 [a] (1.57)	747.2 [b] (1.96)	755.3 [a] (1.75)	**	756.1 (1.28)	747.2 (1.57)	***
Last rib backfat (mm)	14.4 (0.23)	13.9 (0.29)	13.9 (0.26)	NS	13.2 (0.19)	14.9 (0.23)	***
_ last rib backfat (mm)	15.3 (0.24)	14.7 (0.31)	14.9 (0.28)	NS	13.9 (0.20)	15.9 (0.25)	***
_ loin depth (mm)	56.9 [a] (0.39)	58.5 [b] (0.49)	57.6 [ab] (0.45)	*	58.3 (0.33)	57.1 (0.39)	*
Estimated lean content (g/kg)	570.9 (2.13)	578.1 (2.71)	574.7 (2.42)	NS	584.2 (1.78)	564.9 (2.17)	***
Carcass weight Distribution							
Loin (g/kg)	37.5 [a] (0.32)	37.4 [a] (0.39)	39.3 [b] (0.36)	***	39.2 (0.26)	36.9 (0.32)	***
Leg (g/kg)	144.8 [a] (0.49)	142.8 [b] (0.62)	144.7 [a] (0.56)	**	145.9 (0.41)	142.4 (0.49)	***

[a,b,c] LSMeans with different superscripts are significantly different (P<0.05; ** P<0.01; *** P<0.001)*

The progeny of the three terminal sires differed significantly in their live and carcass weight ($P<0.001$), Pi NN-a sired pigs showing the highest weight and Pi NN-b sired pigs the lowest. Pi NN-a sired pigs had a significantly higher loin depth ($P<0.05$) compared with Pi nn sired pigs. Loin yield was significantly higher for Pi NN-b sired pigs ($P<0.001$) than for the progeny of the other two terminal boars. Pi NN-a sired pigs had a lower leg yield ($P<0.01$) than the other two terminal boar sired pigs.

Least square means and standard errors of meat quality traits of the different pre-slaughter treatments, terminal sires and sexes of pigs from Farm 1 and Farm 2 are shown in Tables 4 and 5, respectively. In Farm 1, the long pre-slaughter treatment resulted in significantly higher pHu ($P<0.001$), lower PQM ($P<0.01$) and darker meat (i.e. lower L* minolta value, $P<0.001$) compared with the short pre-slaughter treatment. Minolta b* value was also significantly lower in the long pre-slaughter treatment ($P<0.001$). In Farm 2, these differences were only significant for L* ($P<0.01$) and b* values ($P<0.05$). In both farms, PSE percentage was significantly higher ($P<0.05$) in the short pre-slaughter treatment. Terminal sire had a significant effect on PQM values in both farms, Pi NN-a showing the lowest value in Farm 1 ($P<0.01$) and lower than Pi nn sired pigs and similar to Pi NN-b sired pigs in Farm 2 ($P<0.001$). The effect of terminal sire on PSE incidence was significant in Farm 1, Pi NN-a pigs presenting a significantly lower incidence compared with the other two terminal boar sired pigs. Sex had no significant effect on meat quality traits.

Table 4. Least Square Means and standard errors of meat quality traits of the different transports, terminal sires and sexes in Farm 1

	Pre-slaughter treatment			Terminal sire				Sex		
	Short	Long	*P*	Pi nn	Pi NN-a	Pi NN-b	*P*	Gilts	Barrows	*P*
N	89	90		69	38	72		105	74	
pHu LT	5.5 (0.02)	5.6 (0.02)	***	5.6 (0.02)	5.6 (0.02)	5.6 (0.02)	NS	5.6 (0.01)	5.6 (0.02)	NS
PQM_{24} LT	5.8 (0.36)	4.1 (0.36)	**	5.9 [a] (0.41)	3.7 [b] (0.51)	5.2 [a] (0.40)	**	4.6 (0.33)	5.3 (0.39)	NS
Minolta L [*]	50.9 (0.36)	48.7 (0.36)	***	50.2 (0.41)	49.0 (0.51)	50.3 (0.41)	NS	49.7 (0.33)	49.9 (0.40)	NS
Minolta a [*]	8.3 (0.15)	8.1 (0.15)	NS	8.4 (0.17)	8.0 (0.22)	8.1 (0.17)	NS	8.2 (0.14)	8.1 (0.17)	NS
Minolta b [*]	-0.6 (0.08)	-0.9 (0.08)	***	- 0.6 (0.09)	- 0.9 (0.11)	- 0.7 (0.09)	NS	-0.7 (0.07)	-0.7 (0.09)	NS
Subjective colour	2.9 (0.08)	3.0 (0.07)	NS	2.9 (0.09)	2.9 (0.11)	2.9 (0.08)	NS	2.9 (0.07)	2.9 (0.08)	NS
Loin drip loss (g/kg)	17.7 (0.68)	14.7 (0.69)	NS	16.1 (0.78)	15.3 (0.97)	17.2 (0.76)	NS	16.4 (0.63)	15.9 (0.75)	NS
PSE (%)	6.6	2.8	*	4.4 [a]	0.0 [b]	4.9 [a]	*	5.6	4.0	NS
DFD (%) [†]	0.6	1.6	-	0.6	0.6	1.1	-	1.1	1.1	-

[a,b,c] *LSMeans with different superscripts are significantly different (* P<0.05; ** P<0.01; *** P<0.001)*

[†] *Chi-square could not be calculated for DFD percentage*

Table 5 Least Square Means and standard errors of meat quality traits of the different transports, terminal sires and sexes in Farm 2

	Pre-slaughter treatment			Terminal sire				Sex		
	Short	Long	*P*	Pi nn	Pi NN-a	Pi NN-b	*P*	Gilts	Barrows	*P*
N	114	118		101	68	63		142	90	
pHu LT	5.6 (0.01)	5.6 (0.01)	NS	5.6 (0.01)	5.6 (0.02)	5.6 (0.02)	NS	5.6 (0.01)	5.6 (0.01)	NS
PQM_{24} LT	5.9 (0.34)	5.2 (0.32)	NS	6.5 [a] (0.36)	4.5 [b] (0.44)	4.7 [b] (0.46)	***	4.9 (0.30)	5.6 (0.38)	NS
Minolta L *	49.3 (0.41)	47.9 (0.38)	**	48.9 (0.34)	47.9 (0.52)	49.0 (0.52)	NS	48.4 (0.34)	48.8 (0.44)	NS
Minolta a *	8.7 (0.15)	8.7 (0.14)	NS	8.6 (0.15)	8.6 (0.18)	8.8 (0.19)	NS	8.7 (0.13)	8.7 (0.16)	NS
Minolta b *	-1.0 (0.10)	-1.3 (0.09)	*	-1.2 (0.11)	-1.2 (0.13)	-1.1 (0.14)	NS	-1.2 (0.09)	-1.2 (0.11)	NS
Subjective colour	2.9 (0.07)	3.1 (0.07)	NS	2.9 (0.08)	3.1 (0.09)	2.9 (0.09)	NS	2.9 (0.06)	3.1 (0.08)	NS
Loin drip loss (g/kg)	13.3 (1.03)	13.0 (0.97)	NS	13.9 (1.04)	13.6 (1.26)	11.1 (1.34)	NS	11.8 (0.88)	13.9 (1.10)	NS
PSE (%)	6.2	2.2	*	4.9	1.3	2.2	NS	5.3	3.1	NS
DFD (%)†	0.9	0.9	-	0.4	1.3	0.0	-	1.3	0.5	-

[a,b,c] LSMeans with different superscripts are significantly different (P<0.05; ** P<0.01; *** P<0.001)*

† Chi-square could not be calculated for DFD percentage

DISCUSSION

Physiological measurements

A direct comparison between pre-slaughter treatments is not possible, because of the effect that environmental conditions, circadian rhythms or individual variation could have on the parameters evaluated. It should also be considered that, for practical reasons, the gilts for physiological measurements were transported individually on the upper deck of the truck. Therefore, the transport conditions only partially resembled those encountered in commercial practice and, thus, caution must be taken when extrapolating our results to the commercial situation. The most frequently monitored physiological responses to acute stress are increased secretion of glucocorticoids and increased activity of the sympathetic nervous system, resulting in increased cardiac output. Along that line, no differences between Nn and NN gilts in cortisol increase were found in this experiment. This agrees with previous findings (Nyberg et al., 1988; Shaw et al., 1995; Gispert et al., 2000), but contrasts with other studies (Marple and Cassens, 1973; Fàbrega et al., 2001). Stress assessment using blood indices is likely to present some problems when interpreting the results, because stress systems have been said to be affected differently by the same quality of stressor (Schrader and Ladewig, 1999), the acute cortisol response has been found to vary with the time of stressor application (Ruis et al., 1997) and because there is relatively little information about the exact time responses and half-lives of some of these substances in the blood. Hence, these conflicting results may be partially explained by the biological complexity of the stress response itself. On the other hand, the other measurement of stress recorded in this experiment (i.e. heart rate) was significantly affected by the halothane status of the gilts. Nn gilts showed a significantly higher mean heart rate compared with NN in the short pre-slaughter treatment. Gregory and Wotton (1981) described an exaggerated cardiovascular response for nn pigs, associated with an unusually responsive sympatho-adrenomedullary nervous system. Higher mean heart rate during transport in nn pigs has also been reported by Geers et al. (1994) and, in line with the present findings, in some electrocardiogram parameters in Nn individuals (Villé et al., 1993). This enhanced activity of the sympatho-adrenomedullary system has been said to play an important role in the development of malignant hyperthermia and the higher mortality rates found in nn and Nn pigs subjected to stressful situations (Gregory, 1998).

LDH and CPK levels are commonly used as indicators of muscle damage, even though they can be released into blood under other circumstances such as vigorous exercise. Confirming results in the literature (Honkavaara, 1988; Gispert et al., 2000), CPK level was higher in Nn gilts compared with NN in the short pre-slaughter treatment. Although the difference for LDH was not significant, Nn individuals also tended to experience a higher increase and both measurements combined would imply that transport was a greater physical stress for Nn gilts.

The higher values of mean heart rate confirm loading as one of the peaks of stress of the transport schedule, that may be attributable to climbing the ramps and being handled (Geverink et al., 1998). The fact that in the repeated measurements analysis the time factor had an effect not only on the combined analysis of loading and transport but also on the latter alone indicates that the procedure of transportation also generates stressful stimuli, which agrees with previous investigations (Villé et al., 1993; Geverink et al., 1998). Road conditions, vehicle motion or driving style have been found to influence the level of stress experienced by the transported pigs (Bradshaw et al., 1996). Therefore, a change in those characteristics of the journey may underlie the rises in heart rate during the short transport, even though not enough data was collected to determine the exact cause.

Carcass and meat quality

One of the aims of this study was to evaluate whether some of the advantages of the halothane gene (i.e. carcass lean content or primal cut yield) could be maintained by improved terminal sires free of the gene without compromising meat quality. Provided that the progeny of Pi nn sire line were all heterozygous for the gene and the progeny of the other two boar lines (Pi NN-a and Pi NN-b) were all homozygous negative, terminal sire effects were expected to be partially explained through the halothane status of the individuals. This assumption proved to be partially true for meat quality (PQM values and PSE incidence), being, as expected, poorer for the progeny of Pi nn compared with the progeny of Pi NN-a. This is in agreement with previous findings (McPhee et al., 1994; de Smet et al., 1998; Murray and Johnson, 1998; Fisher et al., 2000; Gispert et al., 2000). The combination of low pH_{45} (i.e. $pH_{45}<6$) with a high muscle temperature leads to denaturation of the sarcoplasmic proteins and this is critical for the formation of PSE pork (Bendall, 1966). As reported previously in other investigations, the n allele had no significant effect

on ultimate muscle pH (García-Macías et al., 1996; Larzul et al., 1997; Gispert et al., 2000). However, the influence of the gene on carcass traits was less noteworthy than in meat quality parameters. As summarised in Table 3, the progeny of nn and NN boars showed few differences in relation to killing out and carcass lean content, and when these differences were significant Pi NN-a sired pigs presented an even higher loin depth compared with the progeny of Pi nn. In relation to primal cut yield, Pi nn sired pigs had a higher leg proportion than Pi NN-a sired pigs, but the difference was not significant in relation to Pi NN-b sired pigs. Overall, these results reinforce the widely acknowledged idea that the halothane gene plays a role in explaining the genetic variation in the technological and eating quality of pork (Sellier and Monin, 1994; de Vries et al., 2000). However, other genes also determine meat and carcass quality and similar results could be obtained from Pietrain halothane free sired pigs in terms of carcass leanness, at least when comparing heterozygous and homozygous negative pigs. As seen in Table 4 and 5, Pi NN-a and Pi NN-b differed in several of the variables compared, what indicates that more research would be required if homogeneous carcass and meat trait standards of the free halothane Pietrain lines are to be established. Recently, an imprinted gene linked to the *IGF2* locus and expressed exclusively from the paternal allele has been said to explain to a large extent the variations of carcass lean content and muscularity, but to have no deleterious effect on meat quality (Nezer et al., 1999). Further research would be required to elucidate how this gene works and its concrete influences in carcass and meat quality and welfare.

There are two other points which can be discussed in relation to the effect of terminal sire on meat quality parameters. Firstly, the fact that terminal sire did not identically behave in both farms (i.e. Pi NN-a and Pi NN-b showed similar results in terms of PQM values and PSE incidence in Farm 2, but Pi NN-b were closer to Pi nn sired pigs in Farm 1 than to Pi NN-a sired pigs). The experimental design does not allow us to disentangle the effects of farm from those of day of sacrifice, and the latter (including pre-slaughter handling procedures and slaughter systems) is considered a source of variation on meat quality grounds. In the present experiment, some of the factors of pre-slaughter handling were the same for both farms (stocking density, truck characteristics, slaughterhouse), but uncontrolled causes of variation may always arise. Therefore, the differences observed between the halothane free terminal sires in both farms could be attributed either to an influence of the farm, the day or sacrifice or to proper differences between NN terminal

sires. As mentioned previously, the development of halothane free Pietrain lines is relatively recent and more work on genetics and selection may be required to define their line standards. Secondly, it should be also discussed the fact that in Farm 1 terminal sire had a significant effect on PSE percentage whereas loin drip losses were not affected. Loins in this study were classified as PSE if they showed a PQM value >6 and L*>53. It has been argued that colour brightness and water-holding capacity may result, at least to some extent, from independent pre-rigor biological phenomena (van Laack et al., 1994; de Smet et al., 1996). In this regard, Warriss and Brown (1987) and van Laack et al. (1994) reported a loose correlation between reflectance and drip losses, describing a biphasic relationship between both variables. In the present study, the lack of correlation between PSE percentage and loin drip losses was not only found when analysing the effect of terminal sire in Farm 1, but also for pre-slaughter treatment in both farms. This could be in accordance with the suggestion that water holding capacity (related to drip losses) and colour brightness (related to PSE assessment in this study) are not totally associated with the same biological phenomena.

Sex effect was, as expected, important on carcass quality but without importance on meat quality. Gilts were found to be leaner and with a higher killing out percentage and primal cut yields than barrows. This is in accordance with other studies (Leach et al., 1996; de Smet et al., 1998; Fisher et al., 2000). As for meat quality, other works have also concluded that the difference between barrows and gilts is small (Ellis et al., 1996; Leach et al., 1996).

Pre-slaughter treatment had an influence on meat quality traits, even though it did not result in a significant interaction between terminal sire and pre-slaughter treatment in the model used. Although only 4 loins in each experiment were classified as DFD, the long pre-slaughter treatment produced darker meat with a significantly higher pHu in Farm 1. Conversely, PQM values and, consequently, PSE prevalence were higher in the short pre-slaughter treatment. Recently, the higher L^* and b^* values and lower pHu found in short pre-slaughter treatments have been related to a higher proportion of myoglobin in the oxygenated form on the surface of the loin (Juncher et al., 2001). Long transport and lairage times have been shown to reduce PSE incidence and improve meat colour, but increase the amount of skin blemish and DFD meat (de Smet et al., 1996; Warriss et al., 1998b). This is in line with the results obtained in the present study. Hence, the practice of increasing on-farm fasting times in order to reduce PSE incidence, may also lead to meat

being downgraded because of DFD condition. With regard to the halothane gene, de Smet et al. (1996) found that the effect of longer lairage was greater in pigs carrying the gene and this is in contrast to the lack of interaction between pre-slaughter treatment and terminal sire in the present study. A previous experiment (Fàbrega et al., 2001) failed to show this interaction as well and it was associated with the fact that the short lairage consisted of 2 hours, which has been recommended as allowing sufficient time to recover from prior stresses (Warriss et al., 1998b), whereas de Smet et al. (1996) offered the pigs a lairage period of <1h. The same interpretation may be true for the present study.

CONCLUSIONS

This investigation suggests that improved halothane-free terminal boars of breeds such as the Pietrain could bring similar benefits in terms of carcass quality (i.e. leanness) without compromising meat quality as halothane positive sires. Long pre-slaughter treatment resulted in a lower incidence of PSE meat but darker meats and higher pHu which could produce a rise in DFD meat. The higher heart rate and CPK observed in Nn gilts indicate that halothane carriers may be more responsive to stressful situations and this could compromise the welfare of those individuals.

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El capítol 4 està basat en

Feeding patterns, performance and carcass traits in group housed growing-finishing pigs: the effect of terminal sire, halothane genotype and age. E. Fàbrega, J. Tibau, J. Soler, J. Fernández, J. Font, D. Carrión, A. Diestre, X. Manteca. Enviat a *Applied Animal Behaviour Science*, gener 2002

CAPÍTOL 4

Feeding patterns, performance and carcass traits in group housed growing-finishing pigs: the effect of terminal sire, halothane genotype and age

ABSTRACT

The effect of terminal sire, halothane genotype and age on feeding patterns and growth performance was studied in 208 castrated growing-finishing pigs distributed in two batches. In Batch 1 (n=130), pigs came from crosses of NN Large White×Landrace sows with a Pietrain Nn (Pi-Nn) or a Large White×Pietrain Nn terminal sire line (LwPi-Nn). In Batch 2 (n=78), the same sows were used but crossed with three different terminal sire lines: a Pietrain nn (Pi-nn), and two Pietrain NN (Pi-NNa and Pi-NNb). Growth performance and feeding patterns of the progeny (Nn or NN for the halothane gene) were measured from 70 to 165 days of age. Pigs were housed in groups of 10 and 13 individuals in Batch 1 and 2, respectively, with a random mixed-breed and halothane genotype sample in each group (space allowance 1.3 m^2/pig and 1.1 m^2/pig, respectively). Feeding patterns were monitored with a computerised food intake recording system (IVOG®-station) and every three weeks pigs were weighed and backfat and loin-muscle depth were ultrasonically recorded (PIGLOG®). Carcass quality was assessed with the Fat-o-Meter grading probe. In Batch 1, halothane genotype did not have a significant effect on any of the feeding patterns recorded, but Nn individuals had a significantly higher body weight (P<0.05), loin-muscle depth (P<0.05) and lower backfat thickness (P<0.01) in the last measurement taken, 3/4 carcass loin depth (P<0.05) and lower carcass last rib backfat (P<0.05) than NN pigs. Terminal sire had a significant effect on all feeding patterns recorded except for feeding rate, Pi-Nn sired pigs showing a significantly higher food intake per visit (P<0.05) and feeder occupation time per visit (P<0.05) and lower number of visits (P<0.001) compared with LwPi-Nn sired pigs which, in turn, showed significantly higher food intake per day (P<0.001) and feeder occupation time per day (P<0.01). Terminal sire also affected growth performance and body composition, Pi-Nn sired pigs having a significantly lower body weight (P<0.001) and backfat thickness (P<0.001), but higher killing out percentage and 3/4 loin depth (P<0.01) than LwPi-Nn sired pigs. In Batch 2, Pi-NNb sired pigs showed a significantly lower food intake per day compared with the progeny of the other two terminal sires in some of the measurements taken

(*P*<0.05). Body and carcass weights (*P*<0.01) were also significantly lower for Pi-NNb sired pigs, but their killing out percentage was higher than Pi-NNa sired pigs. With regard to these variables, Pi-nn sired pigs held an intermediate position between the two NN terminal sire lines. In Batch 2, terminal sire (with a nested effect of halothane genotype) did not significantly affect the rest of the feeding patterns. In both batches, age was associated with a significant increase in food intake per visit and per day and feeding rate (*P*<0.001) and a decrease in feeder occupation time per visit and per day and frequency of visits to the feeder (*P*<0.001). Overall, the present results suggest differences between terminal sire lines for feeding patterns and confirm their evolution with age from short and frequent meals to long and larger ones in growing-finishing pigs. Under our conditions, the effects of terminal sire on feeding patterns and growth performance surpassed those of halothane genotype.

Keywords: Terminal sire line; Halothane gene; Feeding patterns

INTRODUCTION

Differences in performance and carcass and meat quality between breeds and lines of pigs have been widely described (Howard and Smith, 1977; de Haer and de Vries, 1993; Labroue et al., 1999; Augspurger et al., 2002). This variation may be attributed to both genetic and environmental factors and their interaction across the different stages of the pig productive cycle. Genetic effects on feeding behaviour have been studied less. In the past, performance tests of growing pigs were carried out with animals housed individually to enable measurements of food intake and growth rate. This method was not only labour intensive, but also did not reflect the way pigs are kept under commercial practice. Nowadays, the development of computerized food intake recording (CFIR) systems has the potential to resolve these problems to some extent. CFIR systems allow the recording of individual food intake in pigs housed in a group, and thereby include the effects of social interaction. Using this technology, recent studies have reported differences in feeding patterns among purebred pigs like Dutch Landrace and Great Yorkshire pigs (de Haer and de Vries, 1993); Large White and French Landrace (Labroue et al., 1994); Pietrain, Large White and Meishan pigs (Quiniou et al., 1999) and between Pietrain and Large White entire males (Labroue et al., 1999). Augspurger et al. (2002) also found an effect of genetic ancestry on feeding patterns in a synthetic line that included Large White, Landrace, Duroc

and Pietrain, closer to the ones used in commercial situations. Moreover, Labroue et al. (1994) described how feeding patterns could vary in a range from 'meal eaters' (few long meals every day) to 'nibblers' (many short meals), according to the correlations they found between size, duration and daily number of meals.

During the growing period, voluntary feed intake (VFI) has been found to be influenced by many factors such as physiological status (age, body weight) (Kanis and Koops, 1990), type of pig (breed, sex) (Labroue et al., 1999), environmental factors like temperature (Quiniou et al., 2000) and physical activity (Hale et al., 1986). It has also been argued that most pig breeding programs have focused on feed conversion and lean percentage at the expense of growth rate (Labroue et al., 1994). This kind of selection, especially if practiced under *ad libitum* feeding conditions, may lead to a decrease in voluntary feed intake (Smith et al., 1991; Labroue et al., 1994). One of the breeding policies to select for leanness was based on developing meat sire lines including breeds such as Pietrain and Belgian Landrace with a high frequency of halothane gene. Nowadays, the three halothane genotypes (NN, Nn, and nn) can be accurately identified, since Fujii et al. (1991) found the mutation in the Ryr-1 muscle receptor, which is associated with the gene and responsible for a potentially lethal condition known as porcine stress syndrome (PSS). The halothane gene increases stress susceptibility, triggering PSS and increasing the prevalence of pale, soft and exudative meat (PSE), especially in homozygous positive pigs (nn), but also in heterozygous individuals (Nn) (Barton-Gade et al., 1988). Few investigations have been addressed to study a potential effect of halothane gene on voluntary feed intake and feeding patterns. Some studies reported that nn individuals showed a lower growth rate compared with NN (Webb et al., 1982; Sellier, 1987). Moreover, Fernández (2001) found that, although nn pigs spent more time at the feeder and showed a lower feeding rate, there were no differences between NN and Nn pigs in terms of feeding patterns, in agreement with Tor et al's (2001) findings. However, it remains unclear whether a different behavioural feeding strategy among halothane genotypes underlies their results.

The aims of this study were to investigate the effects of terminal sire and halothane genotype on growth performance and feeding patterns. A special endeavour was made to resemble commercial conditions. A single-space CFIR was used that, although different from that found in commercial practice, allows the recording of individual food intake in group housed pigs. Moreover, the halothane genotype comparison was focused on Nn and NN pigs, since the percentage of nn animals in the Spanish pig industry is very low.

MATERIALS AND METHODS

Experimental housing and animals

The experiments were conducted at the Pig Testing Centre (IRTA, Monells, Spain) and consisted of two batches of pigs. One piglet per litter from 6 different farrowing farms of the same commercial producer (140 litters in Batch 1 and 80 litters in Batch 2) was randomly chosen and transported to the Pig Testing Centre at 48-50 days old. The pigs were crosses of the same Landrace×Large-White halothane free (NN) sows, but the terminal sires were different in each batch. Eight boars of each line were used for the inseminations which were carried out within a week in both batches. The halothane genotype of the offspring was determined from a tail sample by amplification and digestion with restriction enzymes as described by Fujii et al. (1991). (The HAL-1983 trademark is licensed from Innovations Foundation, Toronto, Canada).

In Batch 1 (November 1999 to January 2000), the 130 castrates that were used came from two halothane heterozygous terminal sires: a Pietrain (Pi-Nn) and a Large White×Pietrain (LwPi-Nn). The distribution of halothane genotype and terminal sire was: 63 LwPi-Nn sired pigs (32 NN and 31 Nn) and 67 Pi-Nn sired pigs (34 NN and 33 Nn). In Batch 2 (March 2000-June 2000), three different terminal sires were used: a halothane homozygous positive Pietrain (Pi-nn) and two halothane free Pietrain lines (Pi-NNa and Pi-NNb). A total of 31 Pi-nn sired (all Nn for the halothane gene), 23 Pi-NNa and 24 Pi-NNb (all NN) castrates were controlled.

Ventilation and temperature at the Pig Testing Centre were mechanically controlled. Each pen (3.7×3.6 m) had sheeted metal sides, half slatted floor and one drinking bowl. In Batch 1, pigs were kept in groups of 10 and, in Batch 2, in groups of 13, which were composed of a random and balanced mixture of the genotypes and terminal sires studied. Space allowance was 1.3 m^2/pig and 1.1 m^2/pig in Batch 1 and 2, respectively.

Experimental procedure

The pigs were allowed an initial period of 2-3 weeks to acclimatise to the pens and the feeding system before any data on feeding behaviour was recorded. On the first 2 days, a few fresh food pellets were placed on the lip of the trough to encourage the pigs to use the

feeders. The performance test started, then, when animals had an average weight of 28 and 27.6 kg, in Batch 1 and 2, respectively. During the test, the pigs were offered a standard pelleted growers food containing per kg fresh: 177 g crude protein, 14 MJ digestible energy, 38 g crude fibre, 880 g dry matter, 62 g ash, 72 g crude fat.

To record individual food intake, each pen was equipped with an IVOG$^{\hat{a}}$-station (Hokofarm, Marknesse, The Netherlands). The feeding station consisted of a single-space feed hopper and a trough which was weighed continuously and an electronic identification system that was activated by ear responders as the animal entered the station. The feeding station was connected through a load cell to a computer and the trough refilled if the amount of feed after one pig's visit was below 10 kg. At each visit of a pig to the feeder, time and weight of the feed at the beginning and at the end of the visit were recorded automatically, together with the animal identification number. Feed consumption per visit was calculated as the difference between amounts recorded just before and after the visit with an accuracy of 10 g. To enable competition for food, the entrance to the hopper was always open. The pigs were monitored for 70 days in Batch 1 and 77 days in Batch 2, but for statistical analysis only 50 (from 78 to 145 days of age) and 70 days (from 68 to 139 days of age) were considered, respectively.

Pigs were weighed in both batches every 21 days throughout the test period. In addition, in Batch 1, backfat thickness and loin-muscle depth were recorded ultrasonically using the portable equipment PIGLOG 105 version 3.1 (SFK-Technology, Søborg, Denmark). Average daily gain (ADG, g/d) was calculated through the test period for each animal. Pigs were slaughtered when the average pig weight was approximately 105 kg.

Carcass measurements

After an on-farm fasting period of 10 h, the pigs were transported for 45 min at a stocking density of 0.45 m^2/100 kg pig to the abattoir. The pigs were at lairage for 8 h with free access to water. The abattoir used a MIDAS® Stunning System (Stork RMS, Holland), in which the animals are supported on a moving belt conveyor. The animals had electrodes automatically applied for both the head-only stunning (270 V at 800 Hz) and the head-to-chest cardiac arrest (INARCO®, 175 V at 50 Hz). The plant operated at a high line speed (550 pigs/h).

The hot carcass weight was recorded for each carcass 1 h after slaughter and used to calculate the killing out (g/kg) proportion. The following fat and muscle depths (mm) were taken using a Fat-o-Meater grading probe (FOM) on the *Longissimus* muscle at 60 mm from the mid-line on the left side of the carcass: subcutaneous fat thickness measured at the head of the last rib (last rib backfat), subcutaneous fat thickness measured between the 3rd and 4th last ribs (3/4 last rib backfat) and loin muscle depth also measured between the 3rd and 4th last ribs (3/4 loin depth). Estimated lean content (g/kg) was calculated with the FOM predictors (3/4 last rib backfat and 3/4 loin depth) using the official prediction equation for the Spanish pig population (Gispert and Diestre, 1994).

Statistical analysis

The data on feeding behaviour over the 50 or 70-day recording period (Batch 1 and 2, respectively) were processed using Microsoft EXCEL (v. 2000; Microsoft Corporation, 1995) to produce for each animal:

- NVD: mean Number of Visits to the feeder per Day
- TD: mean total eating Time per Day (min)
- FID: mean Food Intake per Day (g)

From these variables, the following ones were derived:

- FIV: mean Food Intake per Visit (g) (=FID/NVD)
- TV: mean Time per Visit (min) (=TD/NVD)
- RFI: mean Rate of Food Intake (g/min) (=FID/TD)

These means were calculated for every 10 days of recording in order to produce 5 (Batch 1) or 7 (Batch 2) repeated measures for each individual, which will be referred to as "ages". Due to some technical problems, it was not possible to carry out these 10 daily recordings on consecutive days for the two last periods in Batch 1. These 10-day period means were analysed, then, by a repeated measures model using the PROC MIXED with the computer software Statistical Analysis System (SAS system for windows, version 8.1, 1999-2000). In Batch 1, the fixed effects included in the model were genotype, terminal

sire, age, box and their interactions. In Batch 2, genotype was not included since, due to the experimental design, each terminal sire gave rise only to one genotype of the offspring. In both batches, box and interactions were removed from the final model since they did not have a significant effect. The covariance structure chosen for both batches was the Autoregressive (AR (1)), since it was the one which best fitted the model according to Schwarz's Bayesian Criterion.

Body weight and backfat thickness and loin-muscle depth were also analysed using the same repeated measures model and covariance structure as the ones described for the feeding patterns.

The effect of terminal sire and halothane genotype on mean average daily gain and carcass measurements was analysed by least-square procedures, using the General Linear Models (GLM). Halothane genotype, terminal sire and its interaction in Batch 1 and terminal sire in Batch 2 were fitted as main effects, using carcass weight as a covariate. The interaction term in Batch 1 was not significant and was removed from the final model.

RESULTS

Effect of halothane genotype, terminal sire and age on feeding patterns

Halothane genotype did not significantly affect any of the feeding patterns controlled in Batch 1 (Table 1).

Terminal sire had a significant effect on several of the variables, both in Batch 1 (Table 2) and Batch 2 (Table 3). In Batch 1, LwPi-Nn sired pigs showed a significantly higher FID ($P<0.001$), NVD ($P<0.001$) in all ages and a significantly higher TD ($P<0.01$) in all ages except for the last one, compared with Pi-Nn sired pigs. Conversely, Pi-Nn sired pigs showed a significantly higher FIV ($P<0.05$) in all ages except the first one and a significantly higher TV ($P<0.05$) in all ages except the last one, compared with LwPi-Nn sired pigs. In Batch 1, terminal sire did not significantly affect RFI. In Batch 2, terminal sire significantly affected FID ($P<0.05$), Pi-NNb sired pigs showing a lower daily food intake compared with the progeny of the other two terminal sires in the fourth and sixth age, compared with Pi-NNa sired pigs in the second age and compared with Pi-nn sired pigs in the last age. Terminal sire in Batch 2 did not significantly affect the rest of the feeding parameters.

Table 1. Means (S.E.) of the 5 measurements at the different ages of the feeding patterns recorded for both genotypes in Batch 1[1]

	Age (days)									
	78-88		89-98		99-108		109-128		129-145	
	NN	Nn	NN	Nn	NN	Nn	NN	Nn	NN	Nn
Food Intake per Day (FID) (g)	1564.88^{a} (26.65)	1550.70^{a} (34.21)	2009.56^{b} (33.45)	1960.05^{b} (38.41)	2238.11^{c} (47.51)	2199.29^{c} (50.27)	2248.86^{c} (45.76)	2221.72^{c} (52.34)	2105.20^{bc} (40.94)	2138.29^{bc} (43.34)
Total eating Time per Day (TD) (min)	69.26^{a} (1.58)	70.93^{a} (1.44)	70.99^{a} (1.76)	71.06^{a} (1.61)	66.13^{a} (1.73)	67.14^{a} (1.78)	54.68^{b} (1.52)	56.24^{b} (1.49)	42.58^{c} (1.31)	45.61^{c} (1.39)
Number of Visits per Day (NVD)	15.74^{a} (0.61)	15.91^{a} (0.72)	16.99^{b} (0.82)	17.09^{b} (0.94)	17.62^{c} (1.11)	17.99^{c} (1.09)	15.61^{a} (1.09)	16.32^{a} (1.09)	14.39^{a} (0.87)	15.23^{a} (0.98)
Rate of Food Intake (RFI) (g/min)	23.3^{a} (0.66)	22.38^{a} (0.64)	29.35^{b} (0.81)	28.47^{b} (0.83)	34.93^{c} (0.97)	33.86^{c} (0.97)	42.95^{d} (1.31)	41.13^{d} (1.32)	51.59^{e} (1.63)	48.80^{e} (1.43)
Food Intake per Visit (FIV) (g)	118.15^{a} (4.68)	118.63^{a} (5.86)	140.82^{b} (5.98)	141.53^{b} (7.60)	156.75^{c} (7.09)	158.79^{c} (9.61)	189.29^{d} (9.18)	179.57^{d} (10.9)	188.17^{d} (12.61)	192.27^{d} (13.63)
Time per Visit (TV) (min)	5.26^{a} (0.23)	5.37^{a} (0.24)	5.06^{a} (0.26)	5.13^{a} (0.27)	4.76^{b} (0.26)	4.88^{b} (0.30)	4.68^{b} (0.26)	4.62^{b} (0.30)	3.85^{c} (0.26)	4.22^{c} (0.32)

[1] *Means with different superscripts are significantly different. Comparisons are made between genotypes within an age and between ages within a genotype*

Table 2. Means (S.E.) of the 5 measurements at the different ages of the feeding patterns recorded for both paternal terminal lines in Batch 1[1]

	Age (days)									
	79-88		89-98		98-108		109-128		129-145	
	Pi-Nn	LwPi-Nn	Pi-Nn	LwPi-Nn	Pi-Nn	LwPi-Nn	Pi-Nn	LwPi-Nn	Pi-Nn	LwPi-Nn
FID (g)[2]	1494.33^{a} (27.34)	1625.51^{b} (31.63)	1878.42^{c} (30.15)	2098.73^{d} (36.59)	2083.84^{df} (40.84)	2362.75^{e} (50.65)	2117.22^{d} (44.23)	2361.28^{e} (49.24)	2029.23^{f} (36.38)	2219.6^{g} (44.60)
TD (min)	67.56^{a} (1.49)	72.76^{b} (1.46)	67.87^{a} (1.61)	74.39^{b} (1.67)	63.49^{c} (1.67)	69.97^{a} (1.75)	53.61^{d} (1.32)	57.40^{e} (1.66)	42.84^{f} (1.23)	45.37^{f} (1.49)
NVD	13.65^{a} (0.48)	18.14^{bd} (0.72)	13.98^{a} (0.55)	20.28^{c} (0.98)	14.45^{a} (0.70)	21.36^{c} (1.27)	13.18^{a} (0.82)	18.92^{b} (1.23)	13.17^{a} (0.82)	16.55^{d} (0.99)
RFI (g/min)	22.87^{a} (0.69)	22.82^{a} (0.61)	28.79^{b} (0.86)	29.06^{b} (0.77)	34.06^{c} (0.97)	34.76^{c} (0.97)	41.11^{d} (1.32)	43.06^{d} (1.30)	49.27^{e} (1.41)	51.22^{e} (1.67)
FIV (g)	129.48^{a} (5.24)	106.59^{a} (4.91)	154.92^{b} (6.24)	126.54^{c} (6.94)	171.69^{d} (7.67)	142.94^{e} (8.78)	199.21^{f} (9.76)	168.86^{g} (10.02)	202.82^{f} (12.79)	176.76^{g} (13.27)
TV (min)	5.74^{a} (0.21)	4.86^{b} (0.26)	5.57^{a} (0.23)	4.59^{bcd} (0.29)	5.26^{b} (0.26)	4.35^{cd} (0.29)	5.04^{b} (0.26)	4.24^{de} (0.29)	4.24^{e} (0.26)	3.80^{e} (0.32)

[1] Means with different superscripts are significantly different. Comparisons are made between terminal sires within an age and between ages within a terminal sire
[2] For abbreviations see Table 1.

Table 3. Means (S.E.) of the 7 measurements at the different ages of the feeding patterns recorded for the three paternal terminal lines in Batch 2[1]

	Age (days)											
	68-78			79-88			89-98			99-108		
	Pi-nn	Pi-NNa	Pi-NNb	Pi-nn	Pi-NNa	Pi-NNb	Pi-nn	Pi-NNa	Pi-NNb	Pi-nn	Pi-NNa	Pi-NNb
FID (g)[2]	1221.54^{a} (42.38)	1332.96^{a} (52.53)	1079.83^{a} (47.96)	1501.35^{bc} (67.19)	1677.22^{c} (59.55)	1370.75^{b} (65.52)	1784.42^{d} (79.51)	1928.04^{d} (71.77)	1655.54^{d} (73.12)	2127.26^{e} (85.38)	2137.22^{e} (74.54)	1828.5^{f} (90.95)
TD (min)	52.59^{a} (1.90)	54.72^{ab} (2.63)	47.93^{a} (1.77)	60.12^{b} (2.49)	62.00^{bc} (2.79)	56.17^{b} (3.09)	63.71^{cd} (2.69)	63.28^{c} (3.26)	60.80^{cd} (3.04)	63.01^{bc} (2.61)	57.92^{b} (2.80)	57.09^{b} (2.69)
NVD	20.32^{ad} (1.24)	17.00^{abc} (1.53)	17.93^{abcd} (1.33)	18.48^{b} (1.27)	16.11^{bc} (1.44)	16.28^{bc} (1.32)	16.58^{c} (1.08)	14.84^{c} (1.55)	15.69^{c} (1.16)	18.56^{ab} (1.35)	19.83^{ad} (2.78)	16.81^{ac} (1.44)
RFI (g/min)	23.31^{a} (0.83)	24.75^{a} (0.98)	22.98^{a} (1.06)	25.36^{b} (1.10)	27.76^{b} (1.16)	25.24^{b} (1.31)	28.57^{c} (1.41)	31.52^{c} (1.50)	28.08^{c} (1.40)	34.43^{d} (1.55)	38.37^{d} (2.01)	32.88^{d} (1.71)
FIV (g)	69.57^{a} (4.28)	101.23^{a} (11.75)	72.14^{a} (6.74)	92.27^{b} (6.09)	134.24^{bd} (13.24)	101.32^{b} (8.91)	125.46^{c} (8.76)	175.44^{c} (18.15)	123.77^{c} (10.07)	139.79^{d} (11.40)	156.33^{d} (16.40)	131.64^{cd} (12.10)
TV (min)	3.07^{a} (0.19)	4.25^{a} (0.57)	3.26^{a} (0.29)	3.84^{b} (0.29)	5.10^{b} (0.60)	4.36^{bc} (0.48)	4.64^{c} (0.35)	5.87^{c} (0.70)	4.77^{c} (0.49)	4.19^{bc} (0.32)	4.21^{ab} (0.43)	4.45^{bc} (0.55)

[1] Means with different superscripts are significantly different. Comparisons are made between terminal sires within an age and between ages within a terminal sire
[2] For abbreviations see Table 1

Table 3 (cont.). Means (S.E.) of the 7 measurements at the different ages of the feeding patterns recorded for the three paternal terminal lines in Batch 2[1]

	Age (days)								
	109-118			119-128			129-139		
	Pi-nn	Pi-NNa	Pi-NNb	Pi-nn	Pi-NNa	Pi-NNb	Pi-nn	Pi-Nna	Pi-NNb
FID (g)	2317.39^{g} (82.31)	2285.65^{g} (75.77)	2106.71^{g} (87.49)	3077.48^{h} (94.85)	2917.39^{h} (58.54)	2631.94^{i} (74.97)	2795.04^{j} (66.60)	2643.80^{jk} (69.86)	2496.09^{k} (63.49)
TD (min)	61.37^{bc} (2.53)	56.69^{b} (2.57)	56.62^{b} (2.15)	66.44^{d} (2.63)	62.26^{cd} (2.62)	61.03^{d} (2.12)	51.57^{a} (2.11)	47.72^{a} (2.32)	48.80^{a} (1.98)
NVD	21.28^{ad} (1.63)	21.40^{d} (2.44)	19.99^{d} (1.44)	19.10^{ab} (1.34)	19.49^{ad} (2.21)	19.60^{ad} (1.23)	14.76^{c} (1.02)	15.28^{c} (1.69)	16.09^{c} (1.15)
RFI (g/min)	38.52^{e} (1.66)	41.32^{e} (1.65)	37.62^{e} (1.68)	47.33^{f} (1.82)	48.08^{f} (1.89)	43.93^{f} (1.72)	55.81^{g} (1.88)	57.69^{g} (2.41)	52.50^{g} (2.03)
FIV (g)	144.76^{d} (12.25)	152.46^{d} (15.20)	132.45^{cd} (13.29)	193.39^{e} (14.05)	203.47^{e} (21.04)	159.28^{e} (11.86)	225.85^{f} (13.84)	225.45^{f} (19.91)	182.78^{f} (13.85)
TV (min)	3.84^{ab} (0.28)	3.82^{a} (0.42)	3.87^{ab} (0.56)	4.17^{bc} (0.27)	4.44^{ab} (0.54)	3.94^{ab} (0.45)	4.18^{bc} (0.28)	4.13^{ab} (0.42)	3.65^{ab} (0.32)

[1] Means with different superscripts are significantly different. Comparisons are made between terminal sires within an age and between ages within a terminal sire
[2] For abbreviations see Table 1

Age had a significant and similar effect on all feeding patterns in both batches (all $P<0.001$). The pigs significantly increased their FID over time except for the last age in both batches. FIV and RFI also increased during the entire test period in both batches. Comparing the first age with the middle ones, NVD increased over time and then decreased again in the last age. In Batch 1, TD and TV kept steady over the three first ages and then decreased over the two last ones. In Batch 2, the effect was the same but there was a significant increase from the first age to the second one and, then, a decrease also over the last periods.

Effect of halothane genotype, terminal sire and age on body weight, average daily gain, backfat thickness and loin-muscle depth

In Batch 1 (Table 4), halothane genotype showed a significant effect on body weight in the last measurement taken two days before slaughter ($P<0.05$), Nn pigs being heavier than NN. Mean average daily gain was also significantly higher for Nn compared with NN (0.91±0.01 vs. 0.86±0.01 g/d, respectively, $P<0.01$). Backfat thickness was found to be significantly higher for NN individuals compared with Nn in the last age ($P<0.05$). Conversely, Nn pigs had a significantly higher loin-muscle depth than NN pigs in the last two ages ($P<0.01$).

Terminal sire also had a significant effect on the performance parameters recorded. In Batch 1 (Table 4), LwPi-Nn sired pigs showed a significantly higher live weight than Pi-Nn sired pigs from the third age to the last one ($P<0.001$) and also a significantly higher backfat thickness in all measurements taken ($P<0.001$). Terminal sire did not significantly affect loin-muscle neither depth nor average daily gain. In Batch 2 (Table 5), Pi-NNa sired pigs showed a significantly higher body weight compared with the progeny of the other two terminal sires in all ages except for the first one ($P<0.001$). Pi-nn sired pigs held an intermediate position between the other two terminal sired pigs whereas Pi-NNb sired pigs showed the lowest body weight. Average daily gain was significantly lower for Pi-NNb sired pigs compared with Pi-NNa and Pi-nn sired pigs (0.81±0.01 vs. 0.87±0.01 and 0.92±0.02 g/d, respectively, $P<0.01$).

Table 4. Means (S.E.) of the 6 measurements of body weight, backfat thickness and loin-muscle depth for both genotypes and terminal sires in Batch 1[1]

	Age (days)											
	73		91		111		137		148		166	
Genotype	NN	Nn	NN	Nn	NN	Nn	NN	Nn	NN	Nn	NN	Nn
Body weight (kg)	28.14[a] (0.44)	27.77[a] (0.50)	42.66[b] (0.58)	42.26[b] (0.70)	62.4[c] (0.85)	62.13[c] (0.91)	87.42[d] (1.08)	88.84[d] (1.08)	97.47[e] (1.12)	99.31[e] (1.09)	104.64[f] (1.98)	110.54[g] (1.32)
Backfat thickness (mm)	-	-	6.91[a] (0.17)	6.33[a] (0.19)	9.67[b] (0.22)	9.01[b] (0.23)	11.95[c] (0.28)	11.28[c] (0.28)	12.80[d] (0.33)	12.29[d] (0.28)	13.74[e] (0.52)	12.82[f] (0.49)
Loin-muscle depth (mm)	-	-	37.52[a] (0.31)	38.61[a] (0.45)	44.74[b] (0.46)	45.09[b] (0.62)	49.98[c] (0.58)	51.42[c] (0.59)	51.02[d] (0.62)	54.00[e] (0.60)	53.96[f] (1.16)	56.60[g] (0.91)
Terminal Sire[2]	Pi	LwPi	Pi	LwPi	Pi	LwPi	Pi	LwPi	Pi	LwPi	Pi	LwPi
Body weight (kg)	27.49[a] (0.40)	28.44[a] (0.52)	41.41[b] (0.61)	43.54[b] (0.65)	59.98[c] (0.79)	64.59[d] (0.86)	85.38[e] (0.88)	90.95[f] (1.16)	95.28[g] (0.87)	101.57[h] (1.19)	105.77[i] (1.43)	109.56[j] (2.05)
Backfat thickness (mm)	-	-	6.26[a] (0.18)	6.99[b] (0.18)	8.78[c] (0.22)	9.93[d] (0.21)	10.99[e] (0.25)	12.27[f] (0.29)	11.86[g] (0.29)	13.26[h] (0.31)	12.85[i] (0.49)	13.75[j] (0.52)
Loin -muscle depth (mm)	-	-	38.32[a] (0.40)	37.82[a] (0.38)	45.21[b] (0.56)	44.62[b] (0.52)	51.06[c] (0.58)	50.31[c] (0.59)	52.64[d] (0.65)	52.32[d] (0.63)	56.15[e] (0.95)	54.33[e] (1.18)

[1] *Means with different superscripts are significantly different. Comparisons are made between genotypes or terminal sires within an age and between ages within a genotype or terminal sire*

[2] *Pi= Pi-Nn and LwPi= LwPi-Nn*

Table 5. Means (S.E.) of body weight for the three terminal sires in Batch 2

	Terminal Sire Line		
Age (days)	Pi nn	Pi-NNa	Pi-NNb
67	27.64 (0.65)[a]	29.77 (0.89)[a]	25.80 (0.97)[a]
87	42.79 (1.12)[bc]	46.63 (1.28)[b]	38.65 (1.44)[c]
109	61.85 (1.69)[d]	67.28 (1.96)[e]	56.53 (1.92)[f]
127	79.27 (1.89)[g]	84.52 (1.78)[h]	73.38 (2.13)[I]
143	95.56 (1.81)[j]	101.54 (1.97)[k]	87.96 (2.35)[h]
154	104.15 (1.71)[l]	109.92 (1.99)[m]	96.48 (2.26)[k]

Means with different superscripts are significantly different. Comparisons are made between terminal sires within an age (rows) and between ages within a terminal sire (columns)

Effect of halothane genotype and terminal sire on carcass measurements

As seen in Table 6, halothane genotype in Batch 1 had a significant effect on last rib backfat (P<0.05) and 3/4 loin depth (P<0.05), halothane carriers showing a lower backfat thickness and higher loin depth. Terminal sire significantly affected killing out percentage and 3/4 loin depth (P<0.01), Pi-Nn sired pigs showing a higher value for both variables.

Table 6. Means and standard errors of carcass traits of the different terminal sires and halothane genotypes in Batch 1

	Terminal Sire			Halothane genotype		
	Pi-Nn	LwPi-Nn	*P*	NN	Nn	*P*
Live Weight (kg)	105.77 (1.43)	109.56 (2.05)	*	104.64 (1.98)	110.54 (1.32)	*
Carcass Weight (kg)	78.82 (1.46)	82.60 (1.67)	NS	78.81 (1.54)	82.20 (1.60)	NS
Killing out (g/kg)	767.54 (2.27)	759.35 (2.65)	**	760.87 (2.39)	767.43 (2.51)	NS
Last rib backfat (mm)	14.59 (0.48)	16.25 (0.55)	NS	15.83 (0.5)	14.74 (0.51)	*
_ last rib backfat (mm)	16.41 (0.54)	17.7 (0.63)	NS	17.17 (0.57)	16.74 (0.60)	NS
_ loin depth (mm)	61.66 (0.69)	58.83 (0.79)	**	59.17 (0.72)	61.82 (0.76)	*
Estimated lean content (g/kg)	568.35 (5.05)	552.49 (5.88)	NS	557.72 (5.31)	565.60 (5.57)	NS

** P<0.05; ** P<0.01*

In Batch 2 (Table 7), Pi-NNa and Pi-nn sired pigs had a significantly higher carcass weight compared with Pi-NNb sired pigs ($P<0.01$). Killing out percentage was significantly lower for Pi-NNa sired pigs compared with the progeny of the other two terminal sire lines ($P<0.05$).

Table 7. Means and standard errors of carcass quality traits of the different terminal sires in Batch 2

	Terminal Sire			
	Pi-nn	Pi-NNa	Pi-NNb	*P*
Live Weight (kg)	104.15 (1.71) [a]	109.92 (1.99) [b]	96.48 (2.26) [c]	***
Carcass Weight (kg)	78.16 (1.59) [a]	80.23 (2.05) [a]	70.95 (1.82) [b]	**
Killing out (g/kg)	746.41 (3.06) [a]	734.70 (4.02) [b]	747.09 (3.73) [a]	*
Last rib backfat (mm)	15.32 (0.68)	16.67 (0.90)	14.31 (0.84)	NS
_ last rib backfat (mm)	17.24 (0.71)	18.20 (0.94)	16.58 (0.87)	NS
_ loin depth (mm)	58.08 (1.55)	58.40 (2.04)	53.08 (1.89)	NS
Estimated lean content (g/kg)	555.41 (6.38)	547.49 (8.40)	553.24 (7.79)	NS

Means with different superscripts are significantly different.

DISCUSSION

The present study aimed to investigate the effect of terminal sire and halothane genotype on feeding patterns and growth performance. Since the experimental design included repeated measures over time, the evolution of these parameters at different ages will be discussed as well.

Effect of halothane genotype on feeding patterns, performance and carcass measurements

In Batch 1, halothane genotype did not have a significant effect on any of the feeding patterns measured. This ties in with findings reported by Fernández (2001) who found that, although nn pigs spent more time per day at the feeder and showed a lower feeding rate

compared with NN and Nn, there were no significant differences between NN and Nn pigs. Tor et al. (2001) also reported that NN and Nn pigs behaved in a rather similar way in terms of daily food intake, number of visits and time at the feeder. As mentioned previously, the present study tried to resemble commercial conditions and no data about nn pigs are available to contrast with Fernández's (2001) results. This author attributed his results to a more nervous temperament of nn pigs, which would have impaired their meals, thereby reducing their feeding rate and increasing their daily feeding time in order to achieve their daily food intake. The present results do not provide evidence to support the idea that the n allele in heterozygous pigs results in clearly distinct feeding patterns or in a lower voluntary feed intake associated with selection for leanness, since daily food intake did not significantly differ between genotypes, even though it was smaller for Nn pigs. In this sense, other behavioural studies carried out with the same pigs indicated that the behaviour of Nn and NN may differ when subjected to a novel stimuli, but was quite similar in a social context (Fàbrega et al., 2001, unpublished data). Feeding behaviour has been said to vary considerably when pigs are housed in groups or individually (de Haer and Merks, 1992; Bornett et al., 2000) due to social facilitation, competition or group cohesion. Our results would indicate that social influences surpass the effect of halothane gene in heterozygous pigs, and further research would be required to determine whether differences in feeding patterns between NN and Nn pigs occur when animals are kept individually.

Halothane genotype effect on body weight and composition was only significant in the last measurement taken when the pigs aged 166 days. Although it has been said that halothane gene definitely improves carcass lean content (de Vries et al., 2000), there are controversial results in the scientific literature in relation to the growth performance of Nn pigs. They have been found to show a higher (Larzul et al., 1997) or lower average daily gain (de Smet et al., 1998), and better (McPhee et al., 1994; Leach et al., 1996) or similar food conversion ratios (Larzul et al., 1997; Tor et al., 2001) compared with NN pigs. The present experiment would confirm that Nn pigs do have a higher lean content, also confirmed by the higher loin depth and last rib backfat observed in the Nn carcasses, but this difference only becomes significant at a certain age. Moreover, Nn pigs were found to present a higher body weight the day before slaughter (i.e. last measurement), which may be associated with the better average daily gain found during the test period, as also reported by Larzul et al. (1997).

Effect of terminal sire on feeding patterns, performance and carcass measurements

In Batch 1, terminal sire had a clear effect on feeding patterns, Pi-Nn sired pigs being closer to what Labroue et al. (1994) defined as 'meal eaters' (i.e. less visits per day but longer) and LwPi-Nn to 'nibblers' (i.e. more short visits). Pi-Nn sired pigs also were found to show a lower daily food intake, body weight and greater backfat thickness. These results partially agree with those reported by Howard and Smith (1977), Labroue et al. (1999) and Augspurger et al. (2002), who also found a lower food intake and growth rate for Pietrain pigs. However, these authors described a different feeding strategy consisting in the Large White (Labroue et al., 1999) or the hybrid line (Augspurger et al., 2002) achieving a higher food intake through a greater number of larger meals, with a higher food consumption rate, than the Pietrain pigs. Nevertheless, our results are in line with Quiniou et al. (1999), working with individually kept pigs. These authors reported that Large White entire males and castrates, compared with Pietrain entire males, achieved higher food intakes by means of a smaller number of larger and longer meals, with no difference in food consumption rate. Labroue et al. (1994) provided evidence that the social influence of one breed may alter the feeding patterns of another in a mixed-breed housing situation, like the one in our experiment. Thus, an inter-breed influence could underlie the differences between our results and the studies mentioned using group housed pigs. It has also been said that the feeding patterns displayed by individually penned animals may be the preferred patterns (Nielsen et al., 1995) and that the changes in feeding behaviour observed when pigs are housed in groups may reflect the constraints placed on the individual by the social environment (Nielsen, 1999). If Quinious's et al. (1999) findings, obtained from individually kept animals, are taken as the preferred pattern, then the similarities with our results would indicate a low social pressure on our pigs. Overall, it seems that there is a general agreement with the fact that terminal sire does have an effect on feeding patterns (de Haer and de Vries, 1993; Labroue et al., 1994; Labroue et al., 1999; Quinious's et al., 1999; Augspurger et al. 2002), but its influence may be mediated through other factors such as social context. If flexibility of feeding behaviour is assumed (Nielsen, 1999; Bornett et al., 2000), then there may be certain feeding patterns, such as daily food intake, more consistent and easier to define for each breed and other parameters, such as feeding rate, more flexible, being a response to social or environmental challenges.

In Batch 2, the terminal sires compared were the same in terms of breed (Pietrain), but they differed in their halothane genotype (nn or NN). The results obtained to some extent summarise what has been discussed in relation to the effect of halothane genotype and terminal sire for Batch 1, since the effect of terminal sire (with a nested effect of halothane status) in Batch 2 was restricted to daily food intake and was not significant in all the measurements taken. This may indicate that whereas terminal sire may have an effect on feeding behaviour, even if mediated by social influences, the effect of halothane status is less important, at least when comparing Nn and NN group housed pigs.

Terminal sire influence on growth performance also surpassed that found for halothane genotype. In Batch 1, as expected, Pietrain sired pigs were found to show a lower body weight, but higher killing out and 3/4 loin depth compared with LwPi-Nn, in agreement with previous studies (Howard and Smith, 1977; Labroue et al. 1999; Quiniou et al., 1999; Augspurger et al., 2002). There are few data in the scientific literature on productive parameters of Pietrain NN terminal lines, as they have only been introduced to the breeding stocks recently as an alternative to overcome the drawbacks associated with halothane gene. Two different Pietrain NN pigs were used in this study, so that they could be compared. The carcass traits measured suggest that Pietrain NN could bring similar benefits in terms of carcass quality (i.e. no significant differences in leanness were detected) than Pi-nn sired pigs. In addition, another study on carcass and meat quality parameters using litter mates of the pigs of the present experiment, indicated that Pietrain NN terminal boars compromised meat quality to a lower extent, with regard to PSE percentage (Fàbrega et al., 2001, unpublished data) compared with Pi-nn. Under our conditions, Pi-NNa sired pigs showed a significantly higher body weight, but Pi-NNb a lower body weight compared with Pi-nn sired pigs, whereas carcass weight was only significantly lower for Pi-NNb sired pigs. Thus, research should be carried out to clearly identify the free halothane Pietrain lines that would imply a maintenance of carcass quality alongside an improvement in meat quality.

Effect of age on feeding patterns

The feeding patterns of pigs have been found to change with age, from frequent, short visits to the trough by newly weaned pigs to few, large meals in sows and grow-finish pigs (Bigelow and Houpt, 1988; Young and Lawrence, 1994). The findings obtained in the

present experiment are in line with those reported previously in the literature (Bigelow and Houpt, 1988; Nienaber et al., 1990; Labroue et al., 1994; Nielsen et al., 1995; Hyun et al., 1997; Augspurger et al., 2002), in terms of an increase over time in meal size (i.e. FID and FIV) and a decrease in meal frequency (i.e. TD, TV and NVD). These changes are, then, translated into an increase in feeding rate, as found in our experiment, and may be a result of age-dependent increases in body size and live weight, as well as changes in degree of maturity and level of experience (Nielsen, 1999). Along that line, recent studies have reported positive correlations between the increase in food consumption rate and body weight (Bigelow and Houpt, 1988; Hyun et al., 1997; Augspurger et al., 2002). It was not the aim of the present experiment to establish the relationship between body weight and feeding patterns, but it may also be true, as in the investigations mentioned, that the observed changes in feeding patterns over time may be partially explained by the increases in body weight, which cannot be disentangled from changes in maturity.

CONCLUSIONS

These results suggest differences between terminal sire lines for feeding patterns which may be mediated by social context and exhibited through changes in food intake per visit and per day and frequency. No evidence of a clear effect of halothane allele on feeding strategy in heterozygous pigs was found, indicating that other factors like social environment may be more important. Feeding patterns were found to vary with age based on an increase in meal size and daily food intake and a decrease in frequency and time at the feeder. Under the present conditions, growth performance and body composition were found to be more affected by terminal sire than halothane genotype.

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El capítol 5 està basat en

Effect of the halothane gene on pre-slaughter mortality in two Spanish commercial pig abattoirs. E. Fàbrega, A. Diestre, D. Carrión, J. Font, X. Manteca. Acceptat a *Animal Welfare*, setembre 2001 (en premsa)

CAPÍTOL 5

Effect of the halothane gene on pre-slaughter mortality in two Spanish commercial pig abattoirs

ABSTRACT

A total of 107 ear samples from all the pigs which died during transport or lairage at two commercial abattoirs were collected during two months (February and July), in order to determine their halothane genotype (NN, Nn or nn). The frequencies of the three halothane genotypes among dead pigs were significantly different ($P<0.001$), being 4.7, 24.3 and 71.0% for NN, Nn and nn individuals, respectively. The frequencies of pre-slaughter deaths within each genotype were estimated to be 0.02, 0.09 and 2.29% for NN, Nn and nn genotypes, respectively. According to these results, the removal of both nn and Nn genotypes, would imply an eleven times reduction in the pre-slaughter mortality rate (from 0.22 to 0.02%). It is therefore suggested that from an animal welfare point of view, the elimination of the halothane gene in the existing breeding schemes would have a major beneficial impact.

Keywords: animal welfare, halothane gene, lairage, mortality rate, pig, transport

INTRODUCTION

Mortality during transport is a major welfare concern. Mortality rates in slaughter pigs during transport or lairage are very different among EU countries and vary from 0.03 to 0.5% (Christensen *et al* 1994). Even though transport and environmental conditions which also affect mortality are not the same in those countries (Warriss & Brown 1994), there is no doubt that halothane gene frequencies within the pig population play a major role in such regional variation (Gratz 1981, Christensen *et al* 1994, Guàrdia *et al* 1996).

The halothane gene (Hal) is now considered to be equivalent to the *ryr-1* gene (Fujii *et al* 1991) and pigs homozygous for the mutation in this locus (nn) are assumed to be genetically susceptible to stress, because they are likely to develop a potentially lethal condition known as porcine stress syndrome (PSS). However, the position of heterozygous pigs (Nn) with respect to the other genotypes in terms of meat quality, mortality rate or welfare is still controversial. Recent studies have suggested that any stressful situation such as transport, can trigger the onset of the PSS increasing mortality rates in both genotypes, nn and Nn (Murray & Johnson 1998). These authors found that frequencies of death during lairage and transport were 0.05, 0.27 and 9.2% for the NN, Nn and nn genotypes, respectively. These data are in agreement with findings of other authors obtained from different studies and environmental conditions (Webb *et al* 1982, McPhee *et al* 1994). Moreover, if both nn or Nn pigs are slaughtered under stressful conditions they are prone to produce pale, soft and exudative meat (PSE) (Gispert *et al* 2000). Therefore, selection against halothane gene would have positive implications on welfare and meat quality grounds.

The aim of this survey was to determine the frequency of pre-slaughter deaths within each of the halothane genotypes under commercial conditions, and to evaluate the impact that the removal of this mutation from the Spanish pig population would have on the mortality rate. An especial interest was focused on the position of Nn with respect to the other genotypes, since one of the present breeding programs is to reduce the frequency of nn pigs but increase the frequency of Nn up to 50% in the slaughter pigs.

MATERIALS AND METHODS

Ear samples were collected from all the fattening pigs which died during transport or lairage at two commercial abattoirs, both considered to have a high capacity of slaughter (>500.000 pigs/year). The experiment was carried out during winter (February) and summer (July) of the year 2000. A total of 107 samples were collected. Samples were frozen pending the analysis to determine the halothane genotype (homozygous nn and NN or the heterozygous Nn) by PCR amplification and digestion with restriction enzymes as described by Fujii *et al* (1991). (The HAL-1843 trademark is licensed from Innovations Foundation, Toronto, Canada).

The frequency of pre-slaughter deaths within each genotype (Z) was calculated by means of the formula previously used by Murray and Johnson (1998):

$$Z = (Y*p) / X$$

where, Y is the proportion (%) of pre-slaughter deaths for a specific genotype in the sample or in a specific period or abattoir, p is the mortality rate during transport or lairage in Spain (0.22%, according to Guàrdia *et al* 1996); and X is the frequency (%) of a specific genotype in the commercial kill. These frequencies were obtained from the mean frequency observed at 5 commercial abattoirs surveyed by Gispert *et al* (2000) (42.2, 51.7, 6.2% for NN, Nn and nn pigs, respectively).

Differences between the mortality rates of each genotype were analysed by using the chi-square test with the PROC FREQ technique of SAS/STAT (SAS Institute, Inc, 1988). Data from both sampling months (February and July) and abattoirs have been pooled together in the statistical analysis due to the small number of samples in some of the categories, for instance, the number of NN observations in each abattoir was less than five.

RESULTS AND DISCUSSION

The frequencies of halothane genotypes of pigs dying pre-slaughter during transit or lairage are presented in Table 1. The distribution of halothane frequencies of dead pigs in the two abattoirs was slightly different, mainly concerning the Nn individuals (37.2 vs. 15.6%). This may be attributable to differences in the gene frequency in the slaughtered

animals in both abattoirs, associated with preferences for certain breeds or types of animals. Along that line, Gispert *et al* (2000) surveyed 5 abattoirs and found that the frequency of the halothane allele (n) varied from 54 to 8%. Despite this difference, the number of nn pigs which died during transport or lairage was higher in each abattoir and significantly higher in the combined data ($P<0.001$). Data for both abattoirs combined indicate that 4.7, 24.3 and 71.0% of pigs which died were NN, Nn and nn genotypes, respectively. Therefore, more than two thirds of pre-slaughter deaths may be associated with the presence of the halothane gene. Estimating the frequencies of death within the NN, Nn and nn genotypes as described in the materials and methods section, we obtained 0.02, 0.09 and 2.29%, respectively. Other authors have found similar results, although they suggested different frequencies of death within genotypes. These differences may be related to different pre-slaughter practices and gene frequencies of the population in the surveyed countries (Webb *et al* 1982, McPhee *et al* 1994, Murray & Jonhson 1998). However, there has been a general agreement with the finding that pigs of nn genotype are considerably more prone to die during transit or lairage than pigs of the NN genotype and that Nn pigs hold an intermediate position between both homozygotes.

Table 1. Frequencies of pigs of the three halothane genotypes which died during transport or lairage at two commercial abattoirs

	Abattoirs		
	A	B	Combined[1]
Total number of dead pigs	43	64	107
% NN	2.3	6.3	4.7 [a]
% Nn	37.2	15.6	24.3 [b]
% nn	60.5	78.1	71.0 [c]

[1] *Percentages with different superscripts are significantly different (P<0.05). Chi-square was only calculated for the combined data*

After removal of the Nn and nn pigs from the population an eleven times reduction in mortality rate would be expected (from the 0.22% estimated by Guàrdia *et al* in 1996, to the level of the NN genotype, ie 0.02%). Taking into consideration that in Spain a total of 35.2 million pigs are slaughtered yearly (Anuario Cárnico 1999-2000), and based on the

pre-slaughter death rate of 0.22%, there would be 77.440 pre-slaughter deaths, of which 70.400 could be avoided by the removal of the halothane gene. On the other hand, the elimination of nn slaughter pigs together with an increase of Nn up to 50%, would imply a smaller reduction in the mortality rate compared with eliminating both Nn and nn pigs (from 0.22% to the mean mortality rate of NN and Nn pigs, ie 0.06%).

ANIMAL WELFARE IMPLICATIONS

Even though environmental conditions like temperature and pre-slaughter practices like fasting time influence mortality rate (Warriss & Brown 1994), this experiment suggests that halothane gene has a major detrimental impact on it, both for nn and Nn pigs. In this sense, new breeding possibilities have become available to the pig industry, like the use of improved NN terminal boars. These new strategies leading to the elimination of the "n" frequency in the slaughter pig are expected to decrease mortality rates, bringing alongside important welfare benefits.

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GENERAL DISCUSSION

ABSTRACT

The present study aimed to elucidate whether halothane gene has a real final benefit for the Spanish pig industry, if a broad approach based on carcass and meat quality traits, productivity, mortality and welfare is undertaken. The results obtained indicate that while halothane genotype in Nn pigs may exert a favourable influence on carcass lean content and primal cut yield, it is detrimental to meat quality, mortality and welfare. In contrast, the use of improved terminal sire lines may result in the same benefits on carcass quality grounds, whilst exerting a minor negative influence upon meat quality and welfare. This general discussion summarises the most remarkable findings in relation to the two main factors analysed: halothane genotype and terminal sire. Section 1 deals with the effects of halothane genotype on behaviour and stress physiology. Section 2 is focused on the effects of halothane genotype on carcass and meat quality parameters, productivity and mortality. Section 3 compares the influence of halothane genotype with that of terminal sire on the different variables evaluated. Finally, in section 4 some welfare implications are put forward.

DISCUSSIÓ GENERAL

Des que es van desenvolupar les tècniques de genètica molecular que permeten identificar els tres genotips halotà, l'interès per caracteritzar els porcs Nn ha estat creixent, bàsicament per tal de poder determinar si aquests individus presentaven una relació qualitat de canal versus qualitat de la carn favorable pel sector porcí. En termes generals, els resultats apareguts en la literatura científica coincideixen, tot i que amb certes discrepàncies, en el fet que els beneficis que l'al·lel n aporta en qualitat de la canal van acompanyats d'una depreciació de la qualitat de la carn. Tal i com s'ha esmentat a la introducció, l'actitud d'un sector de consumidors sembla tendir no sols cap a una demanda d'una millor qualitat de la carn, sinó també d'una garantia que certes condicions de benestar animal s'han assolit.

Els objectius d'aquest estudi estaven plantejats per tal d'avaluar els avantatges i inconvenients del genotip halotà, integrant aspectes de qualitat de canal i carn amb d'altres de productivitat i benestar animal, i contrastar-lo amb l'efecte de la línia paterna. En aquesta discussió les dades s'han agrupat en funció d'aquests dos factors principals -genotip halotà i línia paterna- i de la naturalesa dels paràmetres que es van considerar influïts per aquests factors. En aquest sentit, cal tenir presents tres consideracions. En primer lloc, el fet que l'efecte de la línia paterna es va avaluar en relació a la productivitat, la qualitat de canal i carn i el comportament alimentari, però no en el comportament en granja o els paràmetres fisiològics d'estrès. Per tal de fer més comparables els resultats, s'ha dividit els efectes del genotip halotà en dues seccions, la primera amb les variables per les quals només es va avaluar la influència del genotip halotà (apartat 1 de la discussió) i la segona amb les variables on ambdós factors principals van ser considerats (apartat 2 de la discussió). En segon lloc, cal recordar també que els dos lots de porcs estudiats es diferenciaven en les línies paternes, de manera que en el primer lot ambdós mascles terminals (Pietrain i Large White×Pietrain) van donar lloc a descendència dels dos genotips halotà (NN i Nn), mentre que els tres mascles Pietrain utilitzats en el segon lot només donaven lloc a un sol genotip de la descendència. És per aquest motiu, que en el segon lot es van comparar tan sols línies paternes, tenint en compte un possible efecte del genotip halotà inclòs en el de la línia paterna. En tercer lloc, que es van comparar dues línies de

mascles Pietrain NN perquè la seva utilització és relativament recent i encara estan poc caracteritzades en termes productius o de qualitat.

1. EFECTE DEL GENOTIP HALOTÀ EN EL COMPORTAMENT I ELS INDICADORS FISIOLÒGICS D'ESTRÈS

La vinculació del gen de l'halotà amb la productivitat i la qualitat de canal o carn s'ha estudiat força exhaustivament, i les conclusions semblen unitàries en relació als individus nn. En canvi, l'efecte que aquest gen podia exercir sobre el comportament i el benestar animal s'ha assumit més que no pas avaluat a partir del fet que els porcs nn manifestaven els símptomes de la hipertèrmia maligna en situacions definides com a estressants. Els pocs estudis que han analitzat l'efecte del gen de l'halotà en la conducta van aportar indicis que podien existir certes diferències en alguns patrons de comportament (Robert i Dallaire, 1986; Schaefer et al., 1989). Així també les investigacions utilitzant indicadors fisiològics van suggerir que el gen podia estar certament vinculat a una major susceptibilitat a l'estrès (Gregory i Wotton, 1981; Geers et al., 1994; Gispert et al., 2000). Malgrat això, els resultats d'aquests estudis no permetien concloure si es podrien definir "estratègies de comportament" diferenciades per cada genotip, en el sentit que s'ha plantejat a la introducció general d'individus amb resposta més activa o notòria a curt termini davant de l'estrès i d'altres de resposta més passiva.

Tot i que els porcs Nn i NN es van diferenciar en alguns trets concrets, les nostres observacions no van proporcionar evidències clares per concloure que l'al·lel n influeixi d'una manera consistent el comportament social dels porcs, ni en la maternitat ni en l'engreix comercial. Així mateix, les dades recollides en el CCP mitjançant el SACA, tampoc van posar de manifest l'existència de patrons alimentaris diferenciats i consistents pels individus heterozigots o homozigots dominants. Aquests resultats es podrien associar a diverses hipòtesis.

En primer lloc, es podria relacionar amb la controvèrsia sobre el comportament genètic de l'al·lel n en els individus heterozigots pel què fa a trets de qualitat de canal (Sellier i Monin, 1994), que s'ha descrit com a recessiu o additiu (Leach et al., 1996). En aquest sentit, és cert que estudis anteriors havien suggerit que les diferències de comportament més acusades es trobaven entre els dos genotips homozigots (Schaefer et al., 1989; Fernández, 2001), paral·lelament al què s'ha descrit en qüestions de qualitat de carn i canal.

Malgrat això, Schaefer et al. (1989) també van suggerir que els heterozigots presentaven algun tret de conducta distintiu. A més, si bé en les observacions de conducta social o alimentària els individus heterozigots no es van mostrar consistentment diferents del homozigots dominants, els resultats obtinguts en el test d'*Open Field* o les dades de paràmetres fisiològics d'estrès sí que apunten cap a l'existència d'una "reactivitat" o "temperament" diferent dels individus Nn, almenys enfront de situacions que es podrien qualificar d'aversives o noves per l'animal. Tot i que el disseny d'aquest estudi no permet ni estava plantejat per extreure conclusions sobre el comportament genètic de l'al·lel n, aquests resultats semblen indicar que la manca de diferències entre els individus Nn i NN pel què fa a conducta de grup o alimentària caldria associar-la més a d'altres causes que no a una recessivitat absoluta del gen pel què fa a aquests trets.

En segon lloc, el fenotip del comportament, com el de qualsevol altre tret, es pot definir com la suma dels efectes del genotip i de l'ambient, en proporcions que han estat poc quantificades pel què fa als trets de comportament. D'aquesta manera, una de les interpretacions possibles dels resultats dels experiments de comportament, tant en granja comercial com al CCP, seria que altres factors que es podrien englobar en el component ambiental, com l'efecte del grup, l'hora del dia o el període de l'any, van influir més marcadament la conducta que no el genotip halotà. En aquest sentit, cal destacar fenòmens com el de la "facilitació social"-la tendència que manifesten els individus d'un grup a sincronitzar els seus comportaments- a la qual s'ha atribuït un valor adaptatiu (Pulliam i Caraco, 1984). S'argumenta que encara que aquests beneficis evolutius no són necessaris en les condicions productives actuals, els mecanismes de comportament romandrien (Morgan et al., 1999). Les relacions de dominància o les mescles de races de porcs diferents en un mateix grup s'han descrit com a altres influències socials a tenir en compte a l'hora d'interpretar dades de conducta d'animals en grup (Labroue et al., 1994; Morgan et al., 1999). En els experiments que es varen dur a terme, tot i que no es van avaluar factors com la jerarquia, es va analitzar l'efecte del genotip en contextos socials diferents (mescla d'animals de diferent genotip en un mateix grup o grups d'un sol genotip), per tal d'inferir si la manifestació de la influència del genotip estava condicionada pel tipus d'estructura de grup. Els resultats obtinguts indiquen que les diferències puntuals entre individus NN i Nn no es van distribuir preferentment en un tipus de grup (mixt o d'un sol genotip), sinó més aviat d'una manera erràtica en les diferents observacions. A més, en analitzar la influència d'altres factors com "edat"-clarament significativa per tots els paràmetres estudiats- es va

observar una evolució paral·lela per ambdós genotips. En aquest sentit, els resultats que es van obtenir coincideixen amb els apareguts a la literatura: el comportament dels garrins d'ambdós genotips es va caracteritzar per un augment de l'activitat i una disminució paral·lela de la inactivitat al llarg del temps similar als descrits per Blackshaw et al. (1994 i 1997), mentre que l'evolució de la conducta dels porcs d'engreix fou la inversa, coincidint amb Gonyou et al. (1998). Altres factors com l'horari d'observació (matí o tarda) o el període de l'any (estiu o hivern) també van afectar d'una manera significativa la conducta en les observacions en les granges comercials, i d'una manera similar a ambdós genotips. Així, tant els porcs NN com els Nn van manifestar-se més actius a les tardes, fet que s'ha atribuït a un major grau de vigilància o vivacitat en aquesta franja horària (Blackshaw et al., 1997) i molt més actius en l'engreix d'hivern comparat amb el d'estiu, com a conseqüència de l'efecte de la temperatura ambiental. Per tant, es podria concloure que en un context social la conducta dels porcs es veu molt més influïda per factors com l'edat o les condicions ambientals, que no pel genotip halotà.

Quant a l'efecte del gen en la resposta individual i als paràmetres d'estrès, ja s'ha esmentat que els nostres resultats apunten cap a la possibilitat que davant de situacions qualificables d'estressants, els individus NN i Nn responguin d'una manera diferenciada. Malauradament, no es disposa de dades de paràmetres fisiològics de l'experiment d'*Open Field* o d'observacions de comportament pels diferents transports duts a terme. Per tant, la discussió conjunta d'aquests resultats cal entendre-la amb precaució, malgrat que ambdós estímuls es poden considerar com a aversius. No obstant, la interpretació clàssica d'un test d'*Open Field* és que la disminució de la conducta exploratòria reflecteix un nivell d'emocionalitat o por superiors (Broadhurst, 1954). Així el fet que els moviments dels individus Nn en les tres rèpliques del test fossin inferiors, es podria associar a un temperament més "emocional" o a què van experimentar més por. D'altra banda, els increments superiors en els nivells circulants de cortisol, CPK o LDH que van mostrar els porcs heterozigots en alguns dels transports o la seva freqüència cardíaca significativament més alta en un dels experiments, es relacionaria amb una resposta d'estrès psicològic o físic més acusada.

El fet que els resultats no fossin coincidents per tots els transports, s'explicaria a partir de la complexitat de la pròpia resposta d'estrès. Els indicadors fisiològics d'estrès estan subjectes no sols a una considerable variabilitat individual (Terlouw et al., 1997), parcialment associada a factors genètics propis de l'individu com el sexe (Desautés et al.,

1997) o a d'altres d'ambientals com l'edat (Ruis et al., 1997), sinó també a influències com la intensitat, la naturalesa o l'hora del dia d'aplicació de l'estímul estressant (Ruis et al., 1997). En el cas del cortisol, a més, existeix una clara ritmicitat circadiana en la seva concentració basal. En els experiments de transport, es va fer un esforç per controlar factors com el sexe dels porcs o les condicions de transport i minimitzar possibles diferències en els nivells basals individuals. Alhora les comparacions es van limitar a individus dels dos genotips dintre del mateix transport, per tal de poder assumir un efecte aleatori igual per ambdós genotips d'altres factors ambientals com el tipus de conducció o incidències puntuals al llarg del viatge. Malgrat això, existeix tot un espectre de variabilitat no controlable a la qual caldria atribuir en bona mesura el fet que els valors dels índexs fisiològics estudiats no evolucionessin de manera idèntica en tots els transports. En aquest sentit, un dels aspectes a destacar és que aquest estudi confirma l'àmplia variació individual en la resposta d'estrès, que per alguns paràmetres va ser significativament més notòria en els individus heterozigots. Caldria però una investigació més exhaustiva per avaluar si el genotip halotà s'associa a una major variabilitat individual enfront d'estímuls estressants.

La interpretació conjunta de totes les dades de paràmetres comportamentals i fisiològics suggereix que el genotip halotà en individus heterozigots exerceix una influència inferior a d'altres factors sobre la conducta, quan els porcs estan subjectes a unes condicions que es podrien definir com de baix repte per la seva homeostasi. En canvi, si l'animal s'enfronta a una situació que implica un repte més important, les adaptacions comportamentals i fisiològiques -és a dir: la resposta d'estrès- són més acusades en els individus heterozigots. Això indicaria que els problemes que s'observen durant el maneig o transport d'aquest tipus d'individus no s'explicarien únicament a causa del metabolisme muscular alterat que provoca la hipertèrmia maligna, sinó també a partir d'una major reactivitat enfront d'estímuls estressants.

2. EFECTE DEL GENOTIP HALOTÀ EN ELS PARÀMETRES PRODUCTIUS, EL COMPORTAMENT ALIMENTARI, LA QUALITAT DE LA CANAL I DE LA CARN I LA MORTALITAT

Com s'ha esmentat, els efectes del genotip halotà sobre la productivitat i la qualitat han estat més estudiats que no sobre el comportament i la fisiologia. Tot i que amb controvèrsia pel què fa als individus heterozigots, la conclusió generalitzada és que el gen aporta un millor contingut de magre i de peces nobles en detriment de la qualitat de la carn (Cassens et al., 1975; Oliver et al., 1993; Sellier i Monin, 1994; de Smet et al., 1995; Leach et al., 1996; Fisher et al., 2000; Gispert et al., 2000). Els resultats de les canals que es van obtenir en el lot 1, tant dels animals d'engreix comercial com els del CCP, coincideixen amb aquests autors. Així, en l'engreix comercial es va trobar que els porcs heterozigots van presentar un percentatge de magre i de dues peces nobles (pernil i espatlla) superior, conjuntament amb una prevalença de carns PSE i un percentatge de pèrdues del llom també superior. En els animals engreixats en el CCP, les darreres mesures de profunditat de llom i greix *in vivo*, així com la mesura de profunditat de llom i una de les mesures de greix dorsal de la canal, també van assenyalar un major contingut de magre dels animals heterozigots, tot i que el percentatge estimat en la canal no va ser significativament superior en aquest cas. Recentment, s'ha argumentat que els individus portadors del gen presenten una taxa de creixement de les fibres musculars superior, com a conseqüència principalment d'una capacitat de síntesi proteica i una proliferació de les cèl·lules satèl·lit més elevada, que conjuntament amb una taxa de deposició de greix inferior explicarien el seu superior percentatge de magre (Pedersen et al., 2002).

Un altre aspecte interessant és la manca d'interacció entre el tractament *ante-mortem* i el genotip pel què fa als paràmetres de qualitat de carn. De Smet et al. (1996) van trobar que els porcs homozigots recessius i, en menor mesura els heterozigots, es beneficiaven més de temps d'espera llargs que no els porcs homozigots dominants, en relació a diversos trets de qualitat de carn, com la incidència de carns PSE. Els nostres resultats coincideixen, però, amb els de Pommier et al. (1998), que van considerar que la naturalesa de l'estrès *ante-mortem* imposat en els seus animals podia ser massa moderada per induir diferències entre individus heterozigots i homozigots dominants. Segons les nostres observacions del lot 1, els paràmetres fisiològics mesurats *post-mortem* indiquen que els porcs heterozigots van manifestar una resposta d'estrès més marcada al maneig previ al sacrifici. A més, el tipus

de tractament (llarg o curt) també va influir els paràmetres de qualitat de carn en el sentit esperat, una major incidència de carns PSE en el tractament curt i un pH últim superior i més tendència a les carns DFD en el tractament llarg. Per tant, això indicaria que tot i que el tractament *ante-mortem* va ser suficient per desencadenar una resposta d'estrès diferent pels dos genotips, no ho va ser perquè això es traduís en una interacció d'aquest tractament amb el genotip en relació al percentatge de carns PSE. Cal esmentar també que el temps d'espera en el nostre tractament curt va ser de 2 h, recomanat com a suficient per permetre la recuperació dels animals de les alteracions provocades pel transport (Warriss et al., 1998), mentre que en l'estudi de de Smet et al. (1996) el temps d'espera va ser inferior a 1 h, cosa que també pot explicar les diferències de resultats.

Pel què fa l'efecte del gen en els paràmetres de productivitat, en granja comercial en el primer lot no es van observar diferències significatives en els pesos inicials ni finals dels dos genotips. En canvi, en les dades recollides al CCP, els animals heterozigots van mostrar un pes final superior al dels NN en la darrera de les pesades al voltant dels 165 dies de vida. El fet que els resultats de granja comercial i del centre de testatge no coincidissin, caldria atribuir-lo, d'una banda, a la influència dels factors ambientals (temperatura, humitat, densitat). En aquest sentit, sembla lògic que el potencial genètic dels individus s'expressi en major mesura si les condicions ambientals estan més controlades i els són més favorables, i això condueixi a què, si existeixen diferències entre genotips, siguin més fàcilment detectables. D'altra banda, també cal esmentar que en el CCP es van comparar mascles castrats, mentre que en granja les comparacions van ser de femelles. Tot i que es considera que els mascles castrats són més propers a les femelles que no als mascles sencers en alguns aspectes, el sexe suposa un factor inherent a l'individu que condiciona el creixement.

Ja s'ha esmentat que existeix certa controvèrsia en els resultats que comparen els índexs productius dels individus NN i Nn. En les dades obtingudes en el CCP, malgrat que ni el consum mig diari ni els altres paràmetres de conducta alimentària es van veure afectats pel genotip dels animals, es va observar un guany mig diari superior pels individus Nn que no pels NN al llarg del període de control (73-165 dies de vida). Aquest resultat coincideix amb els obtinguts per Pommier et al. (1998), però contrasta amb el d'altres autors que no han trobat diferències significatives entre ambdós genotips (Sather et al., 1991; Pedersen et al., 2002). En aquest sentit, s'ha suggerit que les diferències de creixement entre aquests dos tipus genètics podrien ser dependents de l'edat a la qual es faci la comparació. Així

alguns autors han descrit que els individus Nn creixen més ràpidament entorn de l'edat que els porcs assoleixen el pes de sacrifici (Hanset et al., 1995; Tor et al., 2001), mentre que altres estudis han posat de manifest creixements superiors pels individus lliures del gen en porcs més joves (Rempel et al., 1995; Aubry et al., 2000; Tor et al., 2001). Aquesta evolució coincideix parcialment amb els resultats presentats en aquest treball, en tant que els pesos dels porcs NN i Nn no es van diferenciar significativament fins a la darrera de les pesades a favor dels porcs Nn, tot i que en la primera pesada el pes del porcs NN fou lleugerament superior. Malgrat que l'edat es considera un factor important en l'expressió del creixement, no existeixen estudis exhaustius que avaluïn si el comportament genètic del genotip halotà en relació als índexs productius varia en funció de l'edat o influencia els coeficients d'alometria dels diferents components de l'organisme amb un mecanisme edat-dependent.

En l'experiment que es va dur a terme per estimar la taxa de mortalitat en transport i espera de cada genotip, les diferències entre els tres genotips van ser clares i en la mateixa direcció que els resultats aportats per altres autors (Webb et al., 1982; McPhee et al., 1994; Murray i Johnson, 1998). Els valors concrets de la taxa de mortalitat per cada genotip són diferents en funció de l'estudi, fet que ha estat atribuït a les diferències en les pràctiques de maneig o transport o condicions ambientals prèvies al sacrifici (Warriss i Brown, 1994) o a la pròpia freqüència gènica de les poblacions porcines analitzades en cada cas. Malgrat això, les nostres dades confirmen l'estudi a nivell europeu dut a terme per Christensen et al. (1994), que va suggerir que en països com Dinamarca, on la qualitat de carn havia estat inclosa en els programes de creuament i s'havia pràcticament eliminat el gen de l'halotà , la taxa de mortalitat es va reduir substancialment, en contrast amb països com Alemanya o Bèlgica on la demanda de canals ben conformades era elevada. Les dades que es recullen en aquest treball indiquen que la mortalitat al nostre país també es reduiria considerablement si el gen de l'halotà fos eliminat, fins a 11 vegades en aquest estudi concret.

3. EFECTE DE LA LÍNIA PATERNA SOBRE EL COMPORTAMENT ALIMENTARI, LA PRODUCTIVITAT I LA QUALITAT DE CANAL I CARN

En termes generals, el més important a destacar dels efectes de la línia paterna és que van sobrepassar els del genotip halotà per la majoria dels trets estudiats en relació a la qualitat de canal, productivitat o conducta alimentària, mentre que els seus efectes en la qualitat de carn foren inferiors als del genotip.

D'una banda, la línia paterna va mostrar un efecte sobre els paràmetres de qualitat de la canal, tant en els porcs d'engreix comercial com en els del CCP. Així, en el lot 1, els descendents de la línia paterna Pietrain van mostrar, tal i com calia esperar, un pes canal inferior, però un millor rendiment de canal, percentatge de peces nobles i contingut de magre que no els descendents de la línia híbrida Large White×Pietrain. La raça Pietrain és coneguda per les seves característiques de creixement lent però que resulta en animals molt conformats i amb un contingut de magre molt superior al d'altres races com la Large White. S'argumenta que el seu fèmur més curt contribueix a la forma característica del pernil i un millor rendiment en aquesta peça noble (Wood et al. 1989), i conjuntament amb un menor contingut gastrointestinal, a un millor rendiment de canal. La influència de la raça Pietrain sobre els trets de qualitat de canal sovint s'ha vist estretament vinculada a la del gen de l'halotà, donat que es tracta d'una raça amb una elevada inclusió del gen en la seva població. No obstant, pels motius que s'esmenten a continuació, els resultats obtinguts en aquest estudi indiquen que els efectes d'aquesta raça en relació a un millor contingut de magre no sols estan condicionats pel genotip halotà, sinó també per altres mecanismes o gens actuant de forma additiva o interaccionant amb el de l'halotà. En primer lloc, en el lot 1 la interacció entre línia paterna i genotip halotà no va ser significativa, indicant que el comportament del gen de l'halotà fou similar en ambdues races. Això està en consonància amb altres autors com de Smet et al. (1995), però contrasta en certa manera amb investigacions com la d' O'Brien et al. (1994) que va suggerir que els efectes del gen de l'halotà podien ser raça-dependents. En segon lloc, en el lot 2, on es comparaven tres línies paternes de la raça Pietrain però de diferent genotip halotà, les diferències en contingut de magre no van ser significatives ni en els animals d'engreix comercial ni en els del centre de testatge. Darrerament, s'ha suggerit que un gen associat al locus *IGF2* i que s'expressaria únicament a través de l'al·lel patern podria ser el responsable d'un percentatge important de la variació en contingut de magre (Nezer et al., 1999). Malgrat no conèixer el mecanisme

exacte de funcionament d'aquest gen, sembla que la seva freqüència en races ben conformades com la Pietrain seria elevada i explicaria una part de la muscularitat d'aquests individus. D'aquesta manera, la manca de diferències entre els descendents dels mascles Pietrain nn i Pietrain NN pel què fa a percentatge de magre estimat en el lot 2 podrien associar-se a d'altres gens de la raça diferents a l'halotà.

D'altra banda, els efectes de la línia paterna sobre els índexs productius també foren més pronunciats que no els del genotip halotà. D'aquesta manera, en el primer lot, els descendents de la línia Pietrain engreixats en el CCP van mostrar un pes i una profunditat de greix dorsal inferiors que no els descendents de la línia Large White×Pietrain, i aquesta diferència fou significativa en totes les mesures preses i no únicament en la darrera com en el cas del genotip halotà. Aquests resultats coincideixen amb altres estudis previs (Howard i Smith, 1977; Labroue et al., 1999). En el segon lot, la línia paterna també va influir els pesos dels animals, de manera que els descendents de la línia Pietrain nn van presentar pesos intermitjos entre les dues línies de descendents de Pietrain lliures del gen. Aquest resultat indicaria que caldria més recerca per avaluar les característiques productives i morfològiques de les línies de Pietrain NN i per determinar exactament quines són les que presenten un millor rendiment *in vivo* i en la canal.

Alhora, la línia paterna va influir els paràmetres de conducta alimentària, de manera que, en el lot 1, el consum diari mig fou també inferior entre els descendents de la línia paterna Pietrain. Aquest resultats coincideixen amb la descripció que apareix a la bibliografia de la raça Pietrain com una de creixement lent i de menor ingesta voluntària que no altres com la Large White (Howard i Smith, 1977; Labroue et al., 1999; Augspurger et al., 2002). Malgrat això, altres paràmetres de la conducta alimentària que també es varen veure influïts pel factor línia paterna, no van ser-ho de la mateixa forma que en altres estudis presentats prèviament. Labroue et al. (1999) i Augspurger et al. (2002) van descriure el patró alimentari de la raça Pietrain com a més proper al concepte de "mossegadors" proposat per Labroue et al. (1994), amb una freqüència de visites més elevada però de més curta durada que no els porcs Large White. En canvi, coincidint amb Quiniou et al. (1999), el patró alimentari dels descendents de porcs Pietrain en el nostre estudi fou més aviat de "goluts", amb menys visites a la menjadora però de més durada que no els fills de la línia Large White×Pietrain. Aquest resultat es podria associar amb el què Labroue et al. (1994) van suggerir sobre la interacció entre races que estan allotjades en el mateix grup. Així es podria considerar que els porcs d'origen Pietrain o els Large

White×Pietrain van alterar alguns dels seus patrons de conducta alimentària com a resposta a la influència social de l'altra raça, donat que en aquest estudi convivien en grups mixtes pel què fa a la raça. També s'ha argumentat que els porcs poden mostrar una certa flexibilitat en alguns patrons de conducta alimentària si sorgeixen canvis en el context social o en l'ambient (Nielsen, 1999; Bornett et al., 2000) i que les desviacions de comportament que presenta un individu que conviu en un grup respecte de la seva conducta individual reflecteixen la pressió social a la qual està sotmès (Nielsen, 1999). Per tant, els resultats obtinguts en el nostre estudi indicarien que existeixen alguns patrons de conducta alimentària, com el consum mig diari, més "inelàstics" i consistents per a cada raça, que s'assoleixen mitjançant altres patrons més flexibles, com la freqüència de visites o la velocitat d'ingesta, que cada raça modifica en funció dels canvis ambientals o socials als quals està sotmesa.

Pel què fa al lot 2, les tres línies paternes es van diferenciar només en el consum mig diari, però no en la resta de variables de conducta alimentària, de manera que els descendents de la línia Pietrain NN-b van mostrar un consum inferior. Aquest resultat confirma, d'una banda, la idea que les línies de Pietrain lliures del gen encara no presenten una uniformitat ben fixada, i, d'altra banda, que la conducta alimentària es veu molt més afectada pel factor línia paterna que no pel genotip halotà. Així en el lot 1, el qual les línies paternes eren genèticament més diferents, l'efecte sobre els paràmetres de comportament alimentari va ser molt més rellevant que en lot 2, en el qual les línies paternes compartien una base genètica de raça comú però es diferenciaven en el genotip halotà.

En contrast amb els efectes anteriorment descrits, la línia paterna va afectar en menor mesura que el genotip halotà els paràmetres de qualitat de carn. En aquest sentit, en el primer lot cap variable va mostrar-se influïda per la línia paterna i en el segon lot van sorgir diferències en el valor de conductivitat elèctrica i, en conseqüència, en una de les granges en el percentatge de carns PSE. Caldria destacar, novament, que si bé en una de les dues granges comercials els descendents dels dos grups de Pietrain lliures del gen van mostrar com s'esperava una proporció menor de carns PSE respecte dels descendents de la línia Pietrain nn, en l'altra granja la línia Pietrain NN-b va presentar un comportament més similar en aquest sentit a la línia Pietrain nn que no a l'altra lliure del gen. Això caldria associar-ho de nou a la manca d'una definició homogènia de les línies Pietrain NN.

Comparant els efectes del genotip halotà i de la línia paterna, es pot concloure que els mascles Pietrain NN podrien representar una alternativa al gen de l'halotà interessant, en

tant que els seus descendents mantenen una qualitat de canal comparable a la dels porcs Nn procedents d'una línia Pietrain nn, i el seu efecte sobre la qualitat de carn és menor. Això obriria noves possibilitats de selecció i creuament pel sector porcí. En aquesta línia, però, caldria una investigació més exhaustiva per caracteritzar les línies Pietrain NN. Avaluar altres races com a possibles mascles finalitzadors seria una altra alternativa, tenint en compte que l'efecte de la línia paterna sobre molts del trets mesurats en aquest treball fou considerable.

4. IMPLICACIONS PEL BENESTAR ANIMAL

La repercussió que determinades pràctiques o tractaments poden suposar pel benestar animal resulta sovint complicada per la necessitat d'objectivar científicament un concepte que duu un component subjectiu implícit. Malgrat això, existeix un consens força general sobre el fet que una integració d'aspectes de comportament, fisiològics i productius suposa una bona aproximació per fer inferències sobre benestar animal. D'aquesta manera, els resultats que s'han discutit anteriorment indiquen que el gen de l'halotà pot repercutir negativament sobre el benestar animal per diversos motius.

D'una banda, el fet que la taxa de mortalitat dels porcs nn o Nn durant el transport o espera sigui clarament superior a la dels NN, és un indicador indiscutible que el benestar animal ha estat compromès. La predisposició a desenvolupar la hipertèrmia maligna associada amb l'al·lel n constitueix un problema de benestar, tant si condueix a la mort de l'individu com a la manifestació d'alguns del seus símptomes.

D'altra banda, les troballes del test d'*Open Field* o dels paràmetres fisiològics en relació amb una major reactivitat enfront d'estímuls nous o "estressants" també suposa un argument a favor de possibles problemes de benestar, en tant que vulnera la darrera de les "Cinc Condicions". En l'actualitat, el concepte estrès comporta unes connotacions negatives, perquè el seu ús es destina a indicar que la capacitat d'adaptació de l'individu ha estat sobrepassada (Terlouw et al., 1997). Establir llindars objectius d'acceptabilitat dels mecanismes que un individu ha de posar en marxa per adaptar-se als canvis que li planteja la producció intensiva és complicat, i el cas del concepte d'estrès no és una excepció (Mendl, 1991). En tot cas, al llarg de la vida productiva d'un porc existeixen episodis freqüents enfront dels quals l'individu manifesta una resposta d'estrès. Si en totes aquestes ocasions els animals portadors del gen mostren una resposta més acusada, és probable que

aquests individus posin més de manifest algunes de les conseqüències atribuïdes a l'estrès reiterat, com canvis en alguns perfils hormonals (opioids endògens, prolactina, insulina, hormona del creixement) i en els mecanismes regulats per aquestes hormones, o immunosupressió (Terlouw et al., 1997). És a dir: la major reactivitat dels animals portadors del gen davant de situacions estressants representaria un problema de benestar animal en la mesura que pot induir tota una sèrie de canvis en l'animal que superarien el llindar fisiològic.

D'altra banda, la vinculació de l'estrès amb la hipertèrmia maligna també resulta difícil d'avaluar i quantificar. Alguns autors han postulat que en els individus nn l'activació del múscul pel procés d'atordiment pot ser suficient per induir la formació de les carns PSE, independentment que el maneig previ al sacrifici hagi estat curós (Gregory, 1998). Probablement, per tant, el desencadenant de les reaccions metabòliques a nivell muscular que provoquen la hipertèrmia maligna i les carns PSE està associat primerament al component físic de l'estrès, malgrat que més endavant també pugui aparèixer una resposta d'estrès més generalitzada. En tot cas, tant la major susceptibilitat a la hipertèrmia maligna com la resposta d'estrès incrementada tenen implicacions negatives pel benestar animal, tant si es manifesten conjuntament com pels efectes propis de cadascun d'aquests fenòmens.

Per contra, les observacions del comportament social o alimentari no van evidenciar diferències consistents entre ambdós genotips en la conducta en grup. Això indicaria que els problemes de benestar pels individus heterozigots sorgeixen fonamentalment quan es presenta una situació aversiva o nova per l'animal, i que quan es mantenen en el seus grups habituals responen d'una manera similar als individus lliures del gen als reptes socials o ambientals que se'ls puguin presentar. Així mateix, en aquest estudi no van aparèixer patologies importants per poder determinar si la incidència de certes malalties va ser més freqüent entre un genotip que un altre.

A tall de conclusió, el conjunt dels resultats obtinguts indica que el genotip halotà influeix no sols en el benestar dels animals sinó que també confirma el seu efecte perjudicial sobre la qualitat de carn, paral·lel a un benefici en el contingut de peces nobles i contingut de magre de la canal. Malgrat això, possibilitats com els mascles Pietrain NN avaluats en aquest estudi semblen bones alternatives comercials al gen, en tant que podrien mantenir la qualitat de la canal sense tants efectes negatius sobre la qualitat de carn i amb

una taxa de mortalitat *ante-mortem* considerablement reduïda i una menor repercussió sobre el benestar animal.

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CONCLUSIONS

Genotip halotà :

1. La conducta social dels garrins i dels porcs d'engreix en granja comercial es va veure més influïda per factors ambientals com l'edat dels animals o l'horari d'observació que no pel genotip halotà, l'efecte del qual no fou consistent al llarg de les diferents observacions. La conducta alimentària tampoc es va veure influïda pel genotip halotà dels individus.
2. Els porcs heterozigots van reaccionar davant de la situació nova plantejada per *l'Open Field* test amb una resposta que indicava més por o emocionalitat que no la dels porcs lliures del gen.
3. Els increments superiors de cortisol, CPK o LDH i la freqüència cardíaca significativament més elevada dels porcs heterozigots comparats amb els lliures del gen en alguns dels transports realitzats indica que el genotip Nn va estar associat amb una reactivitat superior a estímuls estressants. Alhora, els resultats suggereixen que els individus heterozigots podrien mostrar una variabilitat individual en la resposta d'estrès superior que no els homozigots dominants.
4. El contingut en magre i peces nobles dels animals heterozigots fou superior, però això també va anar associat amb un percentatge de carns PSE i pèrdues en el llom superior.
5. En l'engreix comercial, el pes final dels animals heterozigots i lliures del gen de l'halotà no es va diferenciar significativament. En els porcs engreixats en el Centre de Control Porcí el pes final i el guany mig diari va ser superior pels individus heterozigots. No obstant, en cap dels dos casos el gen va influir significativament el rendiment de la canal.
6. En condicions comercials, la mortalitat durant el transport i l'espera a l'escorxador va ser clarament superior pels animals homozigots recessius i heterozigots que no pels lliures del genotip halotà. En aquest estudi, les taxes de mortalitat de cada

genotip van ser 2.29, 0.09 i 0.02% pels porcs homozigots recessius, heterozigots i homozigots dominants, respectivament.

Línia paterna:

7. En el primer lot, els efectes de la línia paterna sobre la qualitat de la canal van superar els del genotip halotà, de manera que els descendents de la línia Pietrain van mostrar un rendiment de la canal, contingut de magre i d'algunes peces nobles superior als descendents de la línia Large White×Pietrain. Per contra, la línia paterna no va exercir cap efecte sobre els paràmetres de qualitat de carn.
8. En el segon lot, els resultats de la descendència de la línia Pietrain homozigota recessiva es van situar entre els obtinguts per les dues línies Pietrain lliures del gen pel què fa a alguns trets de qualitat de canal com el rendiment i el pes de pernil o llom. No obstant, la descendència de les tres línies Pietrain no va diferenciar-se en el seu contingut en magre. Pel què fa a qualitat de la carn, el percentatge de PSE de la descendència d'una de les dues línies Pietrain lliures del gen fou inferior al de la descendència de les altres dues línies paternes.
9. Els paràmetres productius també es van veure influïts per la línia paterna. En el primer lot, els descendents del mascle Large White×Pietrain van mostrar un pes i una mesura de greix dorsal *in vivo* superior a la dels descendents de la línia Pietrain. En el segon lot, els descendents de les tres línies Pietrain van mostrar un pes significativament diferent, de manera que els fills de la línia Pietrain homozigota recessiva es van situar entre les dues línies de Pietrain lliures del gen.
10. En relació a la conducta alimentària, en el primer lot, els descendents de la línia Pietrain van tenir un consum diari inferior i una estratègia alimentària basada en menys visites a la menjadora de més durada i més consum comparats amb als descendents de la línia Large White×Pietrain. En el segon lot, les diferències de conducta alimentària van limitar-se a un consum diari inferior dels descendents d'una de les dues línies Pietrain lliures del gen en alguns dels períodes estudiats, però l'estratègia alimentària no va ser influïda per la línia paterna.

Altres factors:

11. Un dejuni perllongat com el dels tractaments *ante-mortem* llargs pot resultar en un percentatge inferior de carns PSE, però en un pHu i una tendència a les carns DFD superiors.
12. Les femelles van mostrar un rendiment de canal, un percentatge de magre i un pes de peces nobles superior al dels mascles castrats. El sexe dels individus no va tenir cap efecte en els paràmetres de qualitat de carn.

General:

13. La comparació dels efectes de la línia paterna i del genotip halotà sobre els diferents paràmetres de comportament, productivitat, qualitat de carn i canal i benestar animal suggereix que les línies Pietrain halotà-negatives podrien ser una bona alternativa al gen de l'halotà , que hauria de ser eliminat de la població porcina per tal d'augmentar la qualitat de la carn i el benestar animal. En aquest cas, caldria un estudi exhaustiu per caracteritzar aquestes línies Pietrain negatives.