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Effect of energy concentration on growth performance and carcass quality of Iberian pigs reared under intensive conditions

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Abstract

In total, 192 Iberian pigs were used to investigate the effects of net energy (NE) concentration of the diet on growth performance and carcass quality of castrated females (CF) and castrated males (CM). From 30 to 112 kg body weight (BW), three diets were formulated with similar digestible amino acid content per kcal of NE but differing in energy concentration (2,045, 2,175 and 2,305 kcal NE kg^{-1} from 30 to 81 kg BW and 2,175, 2,305 and 2,445 kcal NE kg^{-1} from 81 to 112 kg BW). From 112 kg to slaughter (148 kg BW), all pigs received a common finisher diet. Each treatment was replicated eight times and the experimental unit was a pen with four pigs. A decrease in NE concentration of the diet increased feed intake ($p < 0.05$) and tended to impaired feed conversion ratio ($p < 0.10$), whereas carcass and meat quality traits were not affected. Castrated males ate more feed and grew faster but had less fat thickness at the *gluteus medius* muscle than CF ($p < 0.05$). However, no differences in carcass and meat quality traits between genders were detected. We conclude that a reduction in NE content of the grower diets did not affect growth rate and therefore, it not a valuable alternative to avoid excess of BW at slaughter in Iberian pigs reared under intensive management conditions. Also, both genders can be used for the production of high quality carcasses destined to the dry-cured industry.

Additional key words: gender; meat quality; net energy.

Introduction

Traditionally, Iberian (IB) pigs have been reared under extensive production systems with acorns and grass as main nutrient sources. However, because of the limited area of acorn production, only 15-20% of these pigs are currently produced under traditional free-range systems (Daza *et al.*, 2008; Cruz, 2010). Consequently, the development of the Iberian pig industry is based primarily on the production of pigs reared indoors and fed concentrates. Current legislation (BOE, 2007a) allows the use of Duroc sires to improve productive efficiency of IB pigs but the crossbreds must be slaughtered with at least ten months of age. At these ages IB × Duroc pigs fed concentrates are heavier than required by the industry, with poorer feed efficiency and carcasses that are too fat. In addition, because of the heavy body weight (BW), primal cuts are of excessive size and not well adapted to consumer preferences. When IB × Duroc pigs are

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Abbreviations used: a* (redness); ADFI (average daily feed intake); ADG (average daily gain); b* (yellowness); BF (backfat); BF1 (backfat thickness measured perpendicular to the dorsal midline at the level of the last rib); BF2 (backfat thickness measured from 6 cm of the dorsal midline at the level of the last rib); BF3 (backfat thickness measured at the lateral edge of the longissimus dorsi muscle from the skin to the muscle); BW (body weight); c* (chroma); CF (castrated female); CM (castrated male); CP (crude protein); EN (net energy); FCR (feed conversion ratio); GE (gender); GM (gluteus medius muscle); H (high); H° (hue angle); HC (castrated female); IB (Iberian); L (linear); L* (lightness); Lo (low); LM (longissimus dorsi muscle); M (medium); MC (castrated male); NE (net energy); pH_{24} (pH at 24 h post mortem); PV (body weight); Q (quadratic); RH (relative humidity); SEM (standard error of the mean); SM (semimembranosus muscle).

slaughtered at heavy BW, physical feed restriction in the growing period improves trimmed primal cut yields without affecting feed efficiency or meat quality (Serrano *et al.*, 2009a). However, a restriction in feed intake presents some drawbacks, including increased labour requirements at farm level, poor uniformity of carcasses and impaired animal welfare. An alternative to physical feed restriction consists in reducing the energy concentration of the grower diets (from 25-30 to 110-120 kg BW) which might reduce average daily gain (ADG) without affecting carcass and meat quality traits (Kerr *et al.,* 2003). A restriction of energy intake during the final stages of the fattening period is not recommended because of its negative effects on carcass and meat quality traits (López-Bote *et al.*, 2000). Under commercial conditions, relative low net energy (NE) diets are used during the growing phase in IB pigs, whereas energy concentration is increased during the finishing period. In fact, FEDNA (2006) recommends 2,270 kcal NE kg^{-1} from 27 to 100 kg BW and 2,340 kcal NE kg^{-1} from 100 kg of BW to the time of slaughter for IB pigs reared indoors. This practice aims to reduce fatness from 25 to 90-100 kg BW but to increase backfat (BF) of the carcass, fat over the *Gluteus medius* (GM) muscle and intramuscular fat content of the meat at slaughter. This feeding program usually results in better quality of products destined to the dry-cured industry. The effects of energy restriction on growth performance may differ between castrated females (CF) and castrated males (CM) because of differences in voluntary feed intake as well as in body chemical composition. The objective of this research was to study the effect of NE concentration of the diet fed from 30 to 112 kg BW and gender on growth performance and carcass and meat quality of mating Retinto IB × Duroc crossbreds reared indoors and slaughtered at 148 kg BW.

Material and methods

Husbandry and diets

The experimental procedures used were approved by the Animal Ethics Committee of the Universidad Politécnica de Madrid and were in compliance with the Spanish guidelines for the care and use of animals in research (BOE, 2007b). A total of 192 pigs (97 ± 11.1 days of age and 29.7 ± 5.0 kg BW) was used to study the influence of gender (coded CF and CM) and NE content of the diets (low, medium and high) on growth performance and carcass and meat quality. The pigs used were the progeny of Retinto IB dams (Ibergenética Extremeña S.A., Badajoz, Spain) and Danish Duroc sires (El Cantosal, Coca, Segovia, Spain). From birth to the start of the experiment, pigs were managed according to standard commercial procedures. Males were castrated at 4 ± 1 days of age and females were ovariectomized at 58 ± 0.7 days of age (39 days before the beginning of the trial) as indicated by Serrano *et al.* (2009b). Briefly, gilts were immobilized, analgesized and anesthetized and the ovaries were removed through a dorso-lateral incision made in the left site flank by an experienced veterinarian. The pigs were examined daily by farm personnel and weekly by an experienced veterinarian. No further medical intervention was needed in these pigs.

On arrival at the experimental farm, pigs were weighed individually and allotted within gender to 48 pens (four pigs pen^{-1}) on the basis of initial BW (same mean weight per replicate pen). Eight pen replicates per gender were assigned at random to each of the six treatments. Pigs were housed in a naturally ventilated finishing barn with a 70% slatted floor at a space allowance of 1.5 m^2 pig^{-1}. The density used was higher than requested by BOE (2002), because in this research pigs were programmed to be slaughtered at very heavy weights (148 kg BW) and therefore, an extra surface allowance was convenient.

The feeding program consisted of three diets with similar digestible amino acid content per kcal of NE but with different NE concentration from 30 to 81 kg BW (2,045, 2,175 and 2,305 kcal NE kg^{-1}) and from 81 to 112 kg BW (2,175, 2,305 and 2,445 kcal NE kg^{-1}), corresponding to the low, medium and high energy diets, respectively. The medium NE diets were formulated by mixing judiciously the low and the high energy diets. Therefore, little influence of nutrient content of the diet (other than energy) on growth performance and carcass and meat quality should be expected. The diets with medium NE content for each phase corresponded with an energy content close to FEDNA (2006) recommendations for IB pigs. The high and low energy diets, for each of the two growing phases (30 to 112 kg BW) considered, maintained a ±6% difference in energy content with respect to the medium energy diet. From 112 kg to slaughter at 148 kg BW (finishing period), all pigs were fed a

Table 1. Composition of the experimental diets (%, as-fed basis)

	Body weight						
	30-81 kg			81-112 kg			112-148 kg
	Low[1]	Medium	High	Low	Medium	High	2,500 kcal kg^{-1}
Barley	67.70	63.82	60.02	54.49	37.24	20.02	30.22
Wheat	—	6.84	13.67	18.64	32.60	46.56	40.01
Wheat middlings	13.99	8.09	2.18	14.00	12.00	10.00	12.80
Sunflower meal, 30% CP[2]	5.73	2.87	—	4.00	3.06	2.12	—
Soybean meal, 44% CP	6.69	11.10	15.50	3.10	7.22	11.33	6.23
Yellow grease	—	1.33	2.65	1.00	3.02	5.04	6.00
Beet molasses	2.50	2.50	2.50	2.00	2.00	2.00	2.02
Calcium carbonate	1.50	1.41	1.31	1.25	1.20	1.14	1.10
Dicalcium phosphate	0.78	0.95	1.11	0.35	0.54	0.72	0.50
Sodium chloride	0.40	0.42	0.44	0.46	0.48	0.50	0.50
50% L-lysine	0.21	0.16	0.11	0.21	0.14	0.07	0.12
88% OH-methionine	—	0.01	0.01	—	—	—	—
Vitamin and mineral premix[3]	0.50	0.50	0.50	0.50	0.50	0.50	0.50

[1] The net energy (kcal kg^{-1}) of the diets fed from 30 to 81 kg body weight (BW) and from 81 to 112 kg BW was 2,045 and 2,175 for the low, 2,175 and 2,305 for the medium and 2,305 and 2,445 for the high NE diets, respectively. [2] CP = crude protein. [3] Supplied per kilogram of diet: 6,000 IU vitamin A (trans-retinyl acetate); 1,200 IU vitamin D_3 (cholecalciferol); 11 IU vitamin E (all-rac-tocopherol-acetate); 0.5 mg vitamin K_3 (bisulphate menadione complex); 0.2 mg thiamine (thiamine-mononitrate); 2.5 mg riboflavin; 8 mg pantothenic acid (D-Ca pantothenate); 16 mg vitamin B_3 (niacin); 350 mg choline (choline chloride); 0.2 mg pyridoxine (pyridoxine HCl); 0.015 mg vitamin B_{12} (cobalamin); 16 mg Cu ($CuSO_4 \cdot 5H_2O$); 75 mg Fe ($FeSO_4 \cdot 7H_2O$); 40 mg Mn (MnO_2); 110 mg Zn (ZnO); 0.1 mg Co ($CoSO_4$); 0.2 mg Se (Na_2SeO_3); 0.8 mg I [$Ca(IO_3)_2$].

Table 2. Calculated and determined[1] nutrient content of the diets (%, as-fed basis unless otherwise indicated)

	Body weight						
	30-81 kg			81-112 kg			112-148 kg
	Low[2]	Medium	High	Low	Medium	High	2,500 kcal kg^{-1}
Calculated analysis[3]							
Net energy, kcal kg^{-1}	2,045	2,175	2,305	2,175	2,305	2,445	2,500
Digestible Lys	0.56	0.60	0.63	0.47	0.50	0.53	0.45
Digestible Met + Cys	0.40	0.42	0.43	0.37	0.39	0.41	0.37
Digestible Thr	0.35	0.38	0.40	0.29	0.33	0.37	0.30
Digestible Trp	0.13	0.14	0.14	0.12	0.13	0.14	0.12
Determined analysis[4]							
Gross energy, kcal kg^{-1}	3,890	3,930	4,030	3,970	4,080	4,210	4,240
Dry matter	89.8	89.8	90.1	90.1	90.5	90.3	91.3
Total ash	6.0	5.4	5.5	4.7	4.7	4.8	4.4
Crude protein	15.6	16.4	16.8	14.0	15.1	16.6	14.0
Crude fiber	6.6	5.8	6.1	7.4	5.9	4.7	4.6
Ether extract	2.6	3.1	4.8	3.3	5.3	7.1	8.4

[1] In duplicate. [2] The net energy (kcal kg^{-1}) of the diets fed from 30 to 81 kg body weight (BW) and from 81 to 112 kg BW was 2,045 and 2,175 for the low, 2,175 and 2,305 for the medium and 2,305 and 2,445 for the high NE diets, respectively. [3] According to FEDNA (2003). Diets met or exceeded the nutrient requirements recommended by FEDNA (2006). [4] According to AOAC Int (2000).

common diet with 2,500 kcal NE kg^{-1}. Diets were offered for *ad libitum* consumption as 4-mm pellets. The ingredient composition and the calculated (FEDNA, 2003) and determined (AOAC Int, 2000) nutrient content of the diets are shown in Tables 1 and 2, respectively.

Growth performance

Individual BW and feed consumption per pen were recorded at the beginning and at 68, 102 and 141 days on trial and these data were used to calculate ADG, average daily feed intake (ADFI) and feed conversion ratio (FCR). The average daily NE intake and energy conversion ratio were also calculated by period and cumulatively. Pigs that died or were withdrawn from the trial were weighed, and the data were included in the calculation of FCR and energy conversion ratio. Because of excessive ADG during the experiment, pigs had to be slaughtered earlier than planned (eight *vs*. ten months of age and at an average BW of 148 kg). All pigs were slaughtered the same day (238 days of age).

Carcass traits

In vivo measurements. At 112 and 148 kg BW (the evening before slaughter), BF depth and BF area were measured *in vivo* using a real-time ultrasound apparatus (Kretz Tecnick INC, 600 V-V232, Sonovet, Austria) as described by Daza *et al.* (2005). Briefly, BF thickness was measured at three sites; perpendicular to the dorsal midline at the level of the last rib (BF1), 6 cm from the dorsal midline at the level of the last rib (BF2) and at the lateral edge of the *longissimus dorsi* (LM) muscle from the skin to the muscle (BF3). Measurements of the BF area were taken at the level of the last rib and corresponded to the area between the superior face of the LM muscle, the internal face of the skin and the lines that corresponded to BF1 and BF3 measurements. Images were frozen and recorded and the linear and area measurements were taken using the software provided by the real-time ultrasound apparatus. The images of the measurements obtained for chops were digitized, transferred to a portable conventional computer (IBM Thinkpad, Madrid, Spain) and analysed using an AutoCAD program (Autodesk AG, 2009) that was previously calibrated.

Post mortem measurements. The day before slaughter, pigs were fasted for 14 h, weighed individually and transported 50 km to the abattoir (Alfrese, S.A., Segovia, Spain), where they were allowed a 14 h rest period with full access to water but not to feed. Pigs were electrically stunned (225 to 380 V, 0.5 A, 5 to 6 s), exsanguinated, scalded, skinned and eviscerated according to standard commercial procedures. Carcasses were split down the centre of the vertebral column and weighed, and the hot carcass yield was calculated. The head was then removed at the atlanto-occipital junction and the carcasses were blast chilled at 2°C (with an air speed in the chilling room of 1 m s^{-1}) for 2 h. At 2 h *post mortem*, BF depth between the third and fourth last ribs on the middle of the carcass (skin included) and fat thickness over the GM at the thinnest point were measured in the left side of each carcass using a flexible ruler with a precision of 0.5 mm. In addition, the left side of each carcass was used to measure carcass length from the posterior edge of the *Symphysis pubis* to the anterior edge of the first rib, ham length from the anterior edge of the *Symphysis pubis* to the hock joint, tarsus length from the hock joint to the beginning of the hoof, ham circumference at its widest point and tarsus circumference at the mid-point of the bone.

All the carcasses were jointed to yield hams, shoulders and loins according to the simplified EC-reference method (Branscheid *et al.,* 1990) and the weight of these primal parts was measured at 2 h *post mortem* (fresh untrimmed weight). Hams and shoulders were suspended in the air and chilled for 24 h at 4°C. At 24 h *post mortem*, untrimmed hams and shoulders (chilled weight) were weighed again. The difference between weights measured at 2 and 24 h *post mortem* of hams and shoulders was divided by the weight obtained at 2 h to estimate shrink loss (including evaporative loss). Also, an incision was made into the *semimembranosus* (SM) muscle of the left ham and the pH (pH_{24}; 24 h from slaughter) was measured using a Crison pH meter (Crison 507, Crison Instruments S.A., Barcelona, Spain) equipped with a glass electrode (model no. 52-11, Crison Instruments S.A., Barcelona, Spain). Prior to pH measurement, the equipment was calibrated with pH 7.00 ± 0.02 and 4.00 ± 0.02 buffers. Incisions were made through the skin and subcutaneous fat, and the pH probe was inserted into the selected points as described by Stalder *et al.* (1998). At 48 h *post mortem,* hams and shoulders were trimmed of external fat as described by Serrano *et al.* (2009a) and weighed again. Ham and shoulder yields were calculated at 2 and 24 h *post mortem,* and after trimming, whereas loin yield was calculated at 2 h *post mortem*, exclusively.

Hams from all carcasses were ripened for 672 days (salting, postsalting, drying and cellar phases). Salting consisted of rubbing the hams with salt that contained 4.5 ± 1.0% potassium nitrate and 2.5 ± 0.5% sodium nitrate kg^{-1}. Then, the hams were placed in piles that alternated beds of hams and salt for 18 days at 3°C and 90% relative humidity (RH). Afterwards, hams were brushed to eliminate the salt from the surface, hung and left for 70 days in a postsalting chamber at 3.5°C and 77-82% RH. For drying, hams were kept for 35 days at 7-8°C and 70-75% RH and then, stored in a cellar for 549 days at 15-20°C and 60-70% RH. All hams were weighed before and after each stage of the ripening process.

Meat traits

After collection of carcass data, a sample (300 ± 25 g) of LM was excised at the level of the last rib from the left side of all the carcasses from the CM to study the influence of NE concentration of the grower diet on meat quality traits. No samples of LM were collected from CF. The samples were weighed, vacuum packaged and frozen at –20°C for 50 days until subsequent analyses. The day before the analysis, the LM samples were thawed in vacuum package bags for 24 h at 4°C, removed from packages, blotted dry and weighed. Thawing loss was calculated by dividing the difference in weight between the fresh and thawed samples by the initial fresh weight. Additionally, objective measures of pork colour were determined for all thawed chops after a 20 min bloom period using a CM 2002 Minolta chromameter (Minolta Camera, Osaka, Japan) as described by Serrano *et al.* (2009b). The average of three random readings per sample was used to measure the lightness (L^*) and the two colour coordinates (redness, a^*; yellowness, b^*). Additionally, the chroma (c^*) as $c^* = (a^{*2} + b^{*2})^{1/2}$ and the hue angle ($H°$) as $H° = \arctan(b^* / a^*)$ were calculated as estimators of colour intensity (Wyszcecki & Stiles, 1982). Myoglobin content of the LM was measured in two minced slices from each chop using a spectrophotometer (Beckman DU-640; Beckman Instrument, Fullerton, CA, USA) according to the method described by Hornsey (1956) and modified by Boccard *et al.* (1981). Briefly, a sample (5 g) of minced LM was placed into an extraction vessel containing 20 mL of acetone and 1 mL of water and stirred for 30 s with a glass rod. Afterward, 0.5 mL of 12 M HCl was added and the suspension was kept in the dark overnight in a sealed vessel. After filtration, the absorbance of the filtrate was measured at 510 nm. Each slice was evaluated twice and the results averaged. The concentration of myoglobin (milligrams per gram of fresh muscle weight) was obtained by multiplying the absorbance reading by the factor 8.816 obtained by calibration (Boccard *et al.,* 1981).

Fat, crude protein and moisture content of LM samples were determined using a near infrared transmittance meat analyzer (Infratec 1265, Tecator, Höganäs, Sweden) as described by Serrano *et al.* (2008). As the samples were not trimmed free of intermuscular fat and connective tissue, muscular fat included both inter- and intramuscular fat. Cooking loss and shear force were determined as described by Honikel (1998) and Peinado *et al.* (2008), respectively.

Statistical analysis

Data were analysed as a completely randomized design using the Proc GLM procedure of SAS Inst (1990). The model for growth performance and carcass and meat quality traits included gender, NE concentration of the diets and the interaction. Orthogonal polynomial contrasts were performed to study the linear (L) and quadratic (Q) effects of dietary NE level on the traits studied and to compare the effects of low *vs*. the average of the medium and high NE diets and the medium *vs*. high NE diets. For data on BF depth and BF area obtained by ultrasound, age of the pigs was included as main effect. The experimental unit was the pen for all traits and BW at slaughter was used as a covariate for carcass quality traits. Data in tables are presented as least square means for carcass quality variables and as means for all other traits. An α value of less than 0.05 was considered as significant whereas α values between 0.05 and 0.10 were considered to be a tendency.

Results

No significant interactions between main effects were detected for any of the traits studied and therefore, only main effects are presented.

Growth performance

For the entire experimental period, pigs fed diets with the lowest energy content during the growing phase (30 to 112 kg BW) ate more feed (3.28 *vs*. 3.19 *vs*. 3.21 kg day^{-1}; $p < 0.05$) but less energy (7,315 *vs*. 7,401 *vs*. 7,722 kcal NE day^{-1}; $p < 0.01$) and tended to have higher FCR (3.93 *vs*. 3.86 *vs*. 3.79; $p = 0.09$) than pigs fed the medium and high NE diets, respectively (Table 3). Moreover, pigs fed the medium energy diet

Table 3. Effect of net energy (NE) concentration of the diets and gender (GE) on productive performance of the pigs

Item	NE[1]			GE[2]		SEM[3]	*p* value			
	Low (L)	Medium (M)	High (H)	CF	CM		NE	NE: M *vs.* H	NE: L *vs.* M+H	GE
BW, kg										
Beginning of trial	29.9	29.6	29.7	29.5	29.9	1.83	NS	NS	NS	NS
112 days on trial	112.6	110.5	112.7	109.9	113.9	2.37	NS	NS	NS	*
141 days on trial	147.8	146.2	149.5	145.2	150.4	2.81	NS	NS	NS	*
From 30 to 81 kg BW										
ADG[4], g	769	744	771	742	780	16.2	$Q^{\dagger}$	NS	NS	**
ADFI[5], kg	2.59	2.45	2.50	2.47	2.56	0.0571	$L^{\dagger}Q^{\dagger}$	NS	*	*
FCR[6]	3.38	3.29	3.24	3.32	3.29	0.0690	$L^{\dagger}$	NS	+	NS
ANEI[7], kcal d^{-1}	5,292	5,329	5,754	5,351	5,565	125.9	$L^{***}Q^{\dagger}$	**	*	*
ECR[8], kcal g^{-1}	6.89	7.16	7.47	7.21	7.14	0.151	L^{***}	+	**	NS
From 81 to 112 kg BW										
ADG, g	896	892	899	880	911	24.6	NS	NS	NS	NS
ADFI, kg	3.66	3.65	3.64	3.62	3.68	0.0424	NS	NS	NS	+
FCR	4.10	4.10	4.08	4.13	4.07	0.121	NS	NS	NS	NS
ANEI, kcal d^{-1}	7,958	8,419	8,856	8,335	8,487	98.4	L^{***}	***	***	+
ECR, kcal g^{-1}	8.91	9.46	9.94	9.51	9.37	0.283	L^{***}	+	**	NS
From 30 to 112 kg BW										
ADG, g	812	793	814	788	824	14.2	NS	NS	NS	**
ADFI, kg	2.95	2.85	2.88	2.85	2.94	0.0437	NS	NS	*	*
FCR	3.64	3.60	3.54	3.61	3.57	0.0650	NS	NS	NS	NS
ANEI, kcal d^{-1}	6,414	6,571	7,004	6,562	6,764	102.9	L^{***}	***	***	*
ECR, kcal g^{-1}	7.91	8.29	8.63	8.33	8.22	0.153	L^{***}	*	***	NS
From 112 to 148 kg BW										
ADG, g	903	915	943	905	935	23.4	$L^{\dagger}$	NS	NS	NS
ADFI, kg	4.15	4.08	4.10	4.03	4.19	0.0557	NS	NS	NS	**
FCR	4.60	4.49	4.37	4.47	4.51	0.106	L^{*}	NS	+	NS
ANEI, kcal d^{-1}	10,282	10,126	10,167	9,989	10,394	137.9	NS	NS	NS	***
ECR, kcal g^{-1}	11.41	11.14	10.83	11.07	11.18	0.262	L^{*}	NS	+	NS
From 30 to 148 kg BW										
ADG, g	837	827	850	821	855	13.7	NS	+	NS	**
ADFI, kg	3.28	3.19	3.21	3.18	3.28	0.0358	$L^{\dagger}Q^{\dagger}$	NS	*	***
FCR	3.93	3.86	3.79	3.87	3.85	0.0576	L^{*}	NS	+	NS
ANEI, kcal d^{-1}	7,315	7,401	7,722	7,354	7,606	81.9	L^{***}	***	**	***
ECR, kcal g^{-1}	8.75	8.96	9.11	8.97	8.92	0.134	L^{*}	NS	*	NS

NS: not significant; † $p < 0.10$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. L, Q: linear and quadratic effect of NE concentration of the diet, respectively. The interaction NE × GE was NS ($p > 0.10$). Orthogonal contrasts were performed for effects of dietary NE level. The net energy (kcal kg^{-1}) of the diets fed from 30 to 81 kg body weight (BW) and from 81 to 112 kg BW was 2,045 and 2,175 for the low, 2,175 and 2,305 for the medium and 2,305 and 2,445 for the high NE diets, respectively. All pigs received a common diet with 2,500 kcal NE/kg from 112 to 148 kg BW. [2] CF: castrated females; CM: castrated males. [3] SEM: standard error of the mean (eight pens of four pigs each per treatment). [4] ADG: average daily gain. [5] ADFI: average daily feed intake. [6] FCR: feed conversion ratio. [7] ANEI: average NE intake. [8] ECR:energy conversion ratio.

tended ($p = 0.09$) to have lower ADG than pigs fed the high energy diet. From 30 to 81 kg BW, pigs fed the medium energy diet ate less feed (2.45 *vs.* 2.50 kg day^{-1}; $p < 0.05$), and energy (5,329 *vs.* 5,754 kcal day^{-1}; $p < 0.05$) and tended to have higher FCR (3.29 *vs.* 3.24; $p = 0.08$) but lower energy conversion ratio (7.16 *vs.* 7.47 kcal g^{-1}; $p < 0.01$) than pigs fed the high energy diet. From 81 to 112 kg BW, energy concentration of the diet did not affect ADG, ADFI or FCR. However, NE intake increased (L, $p < 0.001$) with increases in NE concentration of the diet. Also, energy conversion ratio was lower (L; $p < 0.01$) for the low energy than

Table 4. Effect of net energy (NE) concentration of the diets, gender (GE) and age on backfat (BF) thickness and area measured *in vivo* by ultrasound of the pigs

Item	NE[1]			GE[2]		Age		SEM[5]	*p* value				
	Low (L)	Medium (M)	High (H)	CF	CM	199 days[3]	238 days[4]		NE	NE: M *vs.* H	NE: L *vs.* M+H	GE	Age
BF1[6]	31.8	32.5	33.9	33.5	32.0	27.2	38.4	1.72	NS	NS	NS	NS	***
BF2[7]	37.6	39.0	41.3	40.4	38.1	31.9	46.7	2.26	NS	NS	†	NS	***
BF3[8]	39.2	40.1	41.8	41.1	40.0	33.4	47.5	2.34	NS	NS	NS	NS	***
BFA[9]	2,228	2,327	2,452	2,369	2,302	1,857	2,824	152.3	NS	NS	†	NS	***

NS: not significant; † $p < 0.10$; *** $p < 0.001$. The interaction among NE, GE and BW were NS ($p > 0.10$). Orthogonal contrasts were performed for effects of dietary NE level. [1] The net energy (kcal kg^{-1}) of the diets fed from 30 to 81 kg body weight (BW) and from 81 to 112 kg BW was 2,045 and 2,175 for the low, 2,175 and 2,305 for the medium and 2,305 and 2,445 for the high NE diets, respectively. All pigs received a common diet with 2,500 kcal NE kg^{-1} from 112 to 148 kg BW. [2] CF: castrated females; CM: castrated males. [3] 112 kg BW. [4] 148 kg BW. [5] SEM: standard error of the mean (eight pens of four pigs each per treatment). [6] Fat thickness (mm) taken perpendicularly to dorsal mid-line at the level of the last rib. [7] Fat thickness (mm) taken to 6 cm off dorsal mid-line at site of the last rib. [8] Fat thickness (mm) measured at the lateral edge of *longissimus dorsi* muscle from the skin to the muscle. [9] Fat area (mm^2) between *longissimus dorsi* muscle superior face, the skin internal face and the lines corresponding to BF1 and BF3.

for the medium and high energy diets. From 112 to 148 kg BW, a period in which all pigs received the same finisher diet, NE of the feed fed in the previous period had no effect on ADFI or energy intake. However, pigs fed the low energy diet in the previous period tended to have ($p = 0.07$) poorer FCR and energy conversion ratio than pigs fed the medium or high energy diets.

For the entire experimental period, CM ate more feed (3.28 *vs*. 3.18 kg day^{-1}; $p < 0.001$) and energy (7,606 vs. 7,354 kcal NE day^{-1}; $p < 0.001$) and had higher ADG (855 *vs*. 821 g; $p < 0.01$) than CF, although no differences were observed between genders for FCR or energy conversion ratio. Consequently, BW at slaughter was higher for CM than for CF (150.4 *vs*. 145.2 kg; $p < 0.05$). From 30 to 81 kg BW (beginning of the experiment to 68 days on trial), CM had higher ADFI ($p < 0.05$) and ADG ($p < 0.01$) and consume more energy ($p < 0.05$) than CF but no differences between genders were observed for FCR or energy conversion ratio. From 81 to 112 kg BW and from 112 to 148 kg BW, CM had higher ADFI and energy intake ($p < 0.10$) than CF but no differences were observed for ADG, FCR or energy conversion ratio.

Carcass and meat traits

Energy content of the grower diets did not affect any of the *in vivo* carcass traits studied (Table 4) and had little effect on the carcass traits studied *post mortem* (Tables 5 and 6). Pigs fed diets with the lowest energy content had more shrink loss (0.65 *vs*. 0.56 *vs*. 0.57%; $p < 0.05$) and lower pH at 24 h (6.27 *vs*. 6.43 *vs*. 6.36; $p < 0.05$) than pigs fed the medium and high energy diets. No differences between CF and CM were observed for BF thickness, carcass yield and loin, trimmed ham and shoulder yields. Shrink loss were lower for CM than for CF (0.55% *vs*. 0.64%; $p < 0.01$) but no differences were observed for ham weight loss during the ripening process. Moreover, CM had less fat at *Gluteus medius* (55.1 *vs*. 56.1 mm; $p < 0.05$) but heavier fresh (17.2 *vs*. 16.6 kg; $p < 0.01$) and chilled (17.0 *vs*. 16.5 kg; $p < 0.01$) shoulders than CF. The BF depth and BF area measured *in vivo* increased ($p < 0.001$) as the BW of the pigs increased. In general, energy content of the grower diets had no effect on any of the meat quality traits studied (Table 7). The only exception was for cooking loss that tended to be lower (Q, $p = 0.08$) in meat from pigs fed the medium energy diet than in meat from pigs fed the high energy diet.

Discussion

Growth performance

Pigs fed the low energy grower diets (30 to 112 kg BW) had higher ADFI and poorer FCR for the entire

Table 5. Effect of net energy (NE) concentration of the diets and gender (GE) on carcass measurements of the pigs

Item	NE[1]			GE[2]		SEM[3]	p value			
	Low (L)	Medium (M)	High (H)	CF	CM		NE	NE: M *vs.* H	NE: L *vs.* M+H	GE
Carcass										
Weight, kg	120.5	118.9	121.8	118.3	122.3	0.51	NS	NS	NS	NS
Yield, %	81.5	81.3	81.5	81.5	81.3	0.28	NS	NS	NS	NS
Fat depth, mm										
Backfat	62.8	63.1	62.8	63.3	62.5	1.00	NS	NS	NS	NS
Gluteus medius	54.9	56.3	55.7	56.1	55.1	0.97	NS	NS	NS	*
Length, cm										
Carcass	85.8	85.7	86.1	85.9	85.9	0.30	NS	NS	NS	NS
Ham	36.7	36.9	36.8	36.5	37.1	0.21	NS	NS	NS	**
Tarsus	15.1	15.0	15.0	15.1	14.9	0.21	NS	NS	NS	NS
Circumference, cm										
Ham	69.5	68.1	68.6	69.0	68.5	0.73	NS	NS	†	NS
Tarsus	17.4	17.3	17.4	17.4	17.3	0.16	NS	NS	NS	NS
Shrink loss, %[4]	0.65	0.56	0.57	0.64	0.55	0.0541	NS	NS	*	**
pH_{24}[5]	6.27	6.43	6.36	6.34	6.37	0.0696	NS	NS	*	NS

NS: not significant; † $p < 0.10$; * $p < 0.05$; ** $p < 0.01$. The interaction NE × GE was NS ($p > 0.10$). Orthogonal contrasts were performed for effects of dietary NE level. [1] The net energy (kcal kg^{-1}) of the diets fed from 30 to 81 kg body weight (BW) and from 81 to 112 kg BW was 2,045 and 2,175 for the low, 2,175 and 2,305 for the medium and 2,305 and 2,445 for the high NE diets, respectively. All pigs received a common diet with 2,500 kcal NE kg^{-1} from 112 to 148 kg BW. [2] CF: castrated females; CM = castrated males. [3] SEM: standard error of the mean (eight pens of four pigs each per treatment). [4] Determined in hams and shoulders, exclusively. [5] pH_{24}: measured at *semimembranosus* muscle at 24 h *post mortem.*

experimental period than pigs fed the medium and high energy diets. However, energy efficiency was reduced as the NE content of the diets decreased. The authors have not found any research conducted with IB pigs that studied the influence of NE concentration of the grower diets on growth performance at slaughter to compare with the results of the current experiment, but similar data have been reported by De La Llata *et al.* (2001) and Yi *et al.* (2010) in conventional white pigs.

Serrano *et al.* (2009a) reported that feed restriction of 82% of *ad libitum* consumption from 42 to 72 kg BW and of 72% from 72 to 112 kg BW reduced ADG without affecting feed efficiency in IB × Duroc pigs reared indoors and slaughtered at 152 kg BW. The feeding strategy used in this last trial resulted in pigs with a BW at ten months of age within the range of BW required by the Iberian pork industry. In the current experiment, however, a 12% decrease in NE concentration of the grower diets failed to reduce BW at slaughter, in agreement with data of Matthews *et al.* (2003) and Apple *et al.* (2004) in conventional white pigs from 27 to 113 kg BW and from 84 to 106 kg BW, respectively. The lack of effect of a reduction in energy concentration of the diet on BW at slaughter could be due to the fact that during the finisher period (112 to 148 kg BW) all pigs were fed a common diet and therefore, the effect of NE concentration of the diet was diluted.

It is generally accepted that growing pigs will adjust ADFI to maintain constant voluntary energy intake under a wide range of dietary energy concentrations (Cole *et al.,* 1967; Ellis & Augspurger, 2001). In the current experiment, from 30 to 81 kg BW and for the entire experimental period an increase in ADFI with decreases in NE content of the diet was observed. Probably, the high capacity of the digestive tract of IB pigs allowed for an increase in feed consumption to cover their energy requirements, irrespective of the NE concentration of the diet. In this respect, Morales *et al.* (2002) reported that from 88 to 108 kg BW, IB pigs had 23% higher voluntary feed intake than Landrace pigs. Therefore, only pigs with small and low capacity ingestion might be candidates for the utilization of a strategy based on low NE diets with the aim to reduce energy intake and growth rate (Beaulieu *et al.,* 2009).

Table 6. Effect of net energy (NE) concentration of the diets and gender (GE) on primal cuts weight and yield of the pigs

Item	NE[1]			GE[2]		SEM[3]	p value			
	Low (L)	Medium (M)	High (H)	CF	CM		NE	NE: M vs. H	NE: L vs. M+H	GE
Ham weight, kg										
Fresh[4]	26.7	26.6	26.6	26.7	26.5	0.21	NS	NS	NS	NS
Chilled[5]	26.5	26.4	26.5	26.5	26.4	0.21	NS	NS	NS	NS
Trimmed[6]	21.0	20.9	21.0	20.9	21.0	0.16	NS	NS	NS	NS
Ham yield, %										
Fresh	22.2	22.4	21.8	22.6	21.7	0.14	NS	†	NS	NS
Chilled	22.0	22.2	21.7	22.4	21.6	0.15	NS	NS	NS	NS
Trimmed	17.4	17.6	17.2	17.7	17.2	0.16	NS	NS	NS	NS
Shoulder weight, kg										
Fresh	16.9	17.0	16.8	16.6	17.2	0.12	NS	†	NS	**
Chilled	16.7	16.8	16.7	16.5	17.0	0.13	NS	†	NS	**
Trimmed	13.0	13.0	12.8	12.8	13.1	0.13	NS	NS	NS	NS
Shoulder yield, %										
Fresh	14.0	14.3	13.8	14.0	14.1	0.15	NS	NS	NS	NS
Chilled	13.9	14.1	13.7	13.9	13.9	0.11	NS	NS	NS	NS
Trimmed	10.8	10.9	10.5	10.8	10.7	0.12	NS	NS	NS	NS
Loin weight[4], kg	4.6	4.5	4.7	4.6	4.7	0.11	NS	NS	NS	NS
Loin yield[4]	3.8	3.8	3.9	3.9	3.8	0.097	NS	NS	NS	NS
Primal cut yield, %										
Fresh[7]	40.0	40.5	39.5	40.5	39.6	0.28	NS	NS	NS	NS
Chilled[8]	35.9	36.3	35.5	36.3	35.5	0.21	NS	NS	NS	NS
Trimmed[9]	28.2	28.5	27.8	28.5	27.9	0.24	NS	NS	NS	NS
Ham weight loss, %										
Salting	4.0	3.9	3.9	3.9	4.0	0.15	NS	NS	NS	NS
Postsalting	8.5	8.5	8.7	8.5	8.6	0.12	NS	NS	NS	NS
Drying	2.2	2.1	2.2	2.1	2.2	0.052	NS	NS	NS	NS
Cellar phase	17.8	16.5	17.7	17.1	17.6	0.84	NS	NS	NS	NS
Ripening[10]	32.5	31.0	32.5	31.6	32.4	0.97	NS	NS	NS	NS

NS: not significant; † $p < 0.10$; ** $p < 0.01$; *** $p < 0.001$. The interaction NE x GE was NS ($p > 0.10$). Orthogonal contrasts were performed for effects of dietary NE level. [1] The net energy (kcal kg^{-1}) of the diets fed from 30 to 81 kg body weight (BW) and from 81 to 112 kg BW was 2,045 and 2,175 for the low, 2,175 and 2,305 for the medium and 2,305 and 2,445 for the high NE diets, respectively. All pigs received a common diet with 2,500 kcal NE kg^{-1} from 112 to 148 kg BW. [2] CF: castrated females; CM: castrated males. [3] SEM: standard error of the mean (eight pens of four pigs each per treatment). [4] Untrimmed weight measured at 2 h *post mortem*. [5] Measured after being suspended in the air for 24 h at 4°C. [6] Measured after trimming. [7] Determined in fresh hams, shoulders and loins. [8] Determined in chilled hams and shoulders after being suspended in the air for 24 h at 4°C. [9] Determined in trimmed hams and shoulders. [10] Entire ripening process.

A second alternative to reduce feed intake in IB pigs could be to increase the fiber content of the diet (for example, inclusion of straw or sugar beet pulp). In IB pig production, feeding low energy diets during the growing period followed by feeding more concentrated diets during the finishing period (FEDNA, 2006) is a common practice used to reduce body fatness during the growing period (25 to 90-100 kg BW), trying to modify the muscle to lipid ratio to improve the quality of carcasses destined to the dry-cured industry. Consequently, fat levels are usually higher for the finishing than for the growing diets.

For the entire experimental period, CM had higher ADFI and ADG than CF. However, no differences between CF and CM were observed for FCR, in agreement with results of Serrano *et al.* (2008, 2009a) with IB × Duroc crossbred pigs and Peinado *et al.* (2012) with crossbreds of Duroc sires and Landrace × Large White dams slaughtered at 119.2 or 131.6 kg BW.

Table 7. Effect of net energy (NE) concentration of the diets on *longissimus dorsi* muscle traits from castrated males slaughtered at 148 kg body weight (BW)

Item	NE[1]			SEM[2]	*p* value		
	Low (L)	Medium (M)	High (H)		NE	NE: M *vs.* H	NE: L *vs.* M + H
Meat colour							
Lightness, L^*	43.7	43.4	43.8	0.62	NS	NS	NS
Redness, a^*	6.6	6.8	6.7	0.31	NS	NS	NS
Yellowness, b^*	12.6	12.4	12.7	0.11	NS	NS	NS
Chroma, c^*	14.3	14.2	14.5	0.15	NS	NS	NS
Hue angle, $H°$	62.4	61.4	61.9	1.22	NS	NS	NS
Myoglobin, mg g^{-1}	1.6	1.5	1.9	0.15	NS	NS	NS
Chemical composition, %							
Fat	9.3	9.3	8.6	0.13	NS	NS	NS
Crude protein	21.0	21.0	21.2	0.14	NS	NS	NS
Moisture	68.8	68.7	69.7	0.25	NS	NS	NS
Water holding capacity, %							
Thawing loss	4.6	3.5	3.3	0.34	NS	NS	†
Cooking loss	10.5	9.5	12.0	0.42	Q†	†	NS
Meat shear force, kg	4.4	3.7	3.8	0.22	NS	NS	NS

NS: not significant; † $p < 0.10$. Q: quadratic effect of NE concentration of the diet. Orthogonal contrasts were performed for effects of dietary NE level. [1] The net energy (kcal kg^{-1}) of the diets fed from 30 to 81 kg body weight (BW) and from 81 to 112 kg BW was 2,045 and 2,175 for the low, 2,175 and 2,305 for the medium and 2,305 and 2,445 for the high NE diets, respectively. All pigs received a common diet with 2,500 kcal NE kg^{-1} from 112 to 148 kg BW. [2] SEM: standard error of the mean (eight pens of four pigs each per treatment).

Carcass and meat traits

In this study, BF depth was measured *in vivo* at 112 kg (before pigs consumed the common finishing diet) and at 148 kg (at slaughter, after all pigs were fed a common finisher diet for 39 days). Although the differences were not significant, BF depth measured *in vivo* was numerically lower in pigs fed the low energy diet than in pigs fed the other two diets. Moreover, BF area tended to be lower in pigs fed the low energy diet than pigs fed the medium and high energy diets. The data indicated that the excess of energy intake in pigs fed the high NE diets was transformed into body fat. In addition, the difference between BF depth of pigs fed the low and high energy diets was higher at 112 kg BW than at 148 kg BW (9.5% *vs.* 6%; data not presented). These results might be explained because from 112 to 148 kg BW all pigs were fed a common diet. In addition, in the current experiment the variability of data on fat measurements obtained with IB pigs was higher than that reported with conventional white pigs. Probably, the high variability found for these variables in IB pigs precluded to detect any significant effects of the increase in energy content of the diet on BF depth measured *in vivo*.

Energy content of the grower diets (30 to 112 kg BW) had little effect on the carcass and meat quality traits studied, in agreement with results reported by Apple *et al*. (2004), Yan *et al.* (2010) and Hinson *et al.* (2011) in conventional white pigs. In the current trial, all diets within a given feeding phase had similar crude protein and amino acid content per unit of energy. Therefore, no differences in carcass fat were expected because of NE concentration of the diet (De La Llata *et al*., 2001; Weber *et al*., 2006). Also, from 112 kg to slaughter at 148 kg BW, all pigs received a common diet. Therefore, the effect of NE of the grower diet on carcass and meat traits might be diluted during the finishing period.

No differences in carcass and trimmed ham yields were found between CF and CM, results that agree with data of Mayoral *et al.* (1999), Ramírez & Cava (2007) and Serrano *et al.* (2008) in IB pigs. Similarly, no differences between CF and CM were observed for BF thickness measured *post mortem,* in agreement with data of Mayoral *et al.* (1999) and Serrano *et al.* (2008, 2009a) in IB pure and crossbreds IB × Duroc pigs, respectively.

The authors have not found any research comparing BF depth of CF and CM measured *in vivo* to compare with the results of the current trial. Fat depth at GM was 1.0 mm higher in CF than in CM, consistent with results of Peinado *et al.* (2008) who reported that CF had 0.8 mm more GM fat depth than CM in crossbreds from Pietrain × Large White sires and Landrace × Large White dams slaughtered at 122 kg BW.

In spite of the higher fat depth at GM of CF as compared with CM, gender did not affect ham weight losses during the ripening process, consistent with data of Serrano *et al.* (2008) comparing intact females and CM crossbreds from IB × Duroc and pure IB pigs. Similarly, Serrano *et al.* (2009a) did not observe any difference in ham weight losses at the end of the curing process between CF and CM.

In conclusion, under the conditions of the current trial, a decrease in net energy concentration of the grower diets was not an useful strategy to reduce growth rate in Iberian × Duroc pigs. Also, castrated males have higher ADG and ADFI than castrated females but both genders are well adapted for the production of high quality carcasses destined to the dry-cured industry.

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