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An analysis of the composition of gain and growth of primal cuts of Iberian pigs of 10 to 150 kg body weight as affected by the level of feeding and dietary protein concentration

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Abstract

A meta-analysis was made of data from a total of 211 growing-finishing Iberian (IB) pigs from four separate and independent sets of trials. Within each set of trials, a factorial arrangement of treatments was used, involving several concentrations of ideal protein in the diets and two or three levels of feed intake. Pigs were slaughtered at several stages of growth from 10 to 150 kg body weight (BW). The partition of dietary protein in the body of the pigs, the empty-body gain (EBG), the chemical composition of EBG, growth of primal cuts in the cold eviscerated carcass (without head, feet, and tail), and mass of dissected tissues in trimmed shoulder and ham were determined. Linear regression equations allowed estimating N requirements for maintenance as $175 \text{ mg}/(\text{kg BW}^{0.75} \cdot \text{kg dry-matter intake}) \cdot \text{d}^{-1}$ and an average value for the net efficiency of utilization of the dietary protein apparently absorbed of 0.386. In pigs offered adequate protein to energy diets, EBG was predicted as a function of average BW and feeding level ($p < 0.001$). Multiple regression equations were constructed, which derived nutrient (g kg^{-1}) or energy (MJ kg^{-1}) composition of EBG as a function of empty-body weight (EBW), dietary protein to energy ratio, and level of feeding ($p < 0.001$). These predictive equations, not applicable to pigs of lean and conventional genotypes, can contribute to the design of optimal feeding strategies to improve the efficiency of IB pig production systems and to achieve high quality standards in end products for the market.

Additional key words: energy intake; feed restriction; protein-to-energy ratio; Iberian barrows.

Introduction

In two recent papers (Nieto *et al.*, 2012, 2013) we have proposed a model to describe the response of the Iberian (IB) pig to protein and energy supply in terms of energy partition into protein and fat deposition and the energetic efficiency of the processes involved, and addressed the estimation of the relative growth of body components of IB pigs under different dietary treatments, involving a wide range of protein concentrations and levels of feeding. It was evident that the low

genetic potential for lean-tissue deposition observed in the IB pig requires the use of specific predictive equations, and that the great differences found in the pattern of relative growth of carcass components in comparison with lean and conventional pig genotypes preclude the application of relationships derived from contemporary pigs to this obese, low-performing breed.

The present study provides additional information to our two previous papers (Nieto *et al.*, 2012 and 2013) that would allow accurate estimations of the chemical composition of empty-body gain (EBG), predic-

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Abbreviations used: AA (amino acid); ADG (average daily gain); ApDN (apparent digestible nitrogen); ApDP:ME (apparent digestible protein-to-metabolizable energy ratio); BW (body weight); CC (cold eviscerated carcass); CP (crude protein); DM (dry matter); EBG (empty-body gain); EBW (empty-body weight); FL (feeding level); GE (gross energy); IB (Iberian); k_f (partial efficiency of ME utilization for fat deposition); k_p (partial efficiency of ME utilization for protein deposition); ME (metabolizable energy); ME_m (ME requirements for maintenance); NI (N intake); N_m (N requirements for maintenance); NR (N retention); PD (protein deposition); PD_{max} (maximum potential for PD); $\Delta PD/\Delta ME$ (marginal efficiency for PD); RSD (residual standard deviation).

tion of size of primal cuts in the carcass of the growing IB pig, and dissected tissues in trimmed shoulders and hams as a function of the nutritional regime imposed. It also describes the partition of dietary protein between maintenance and productive processes in the growing pig fed an adequate supply of amino acids (AA) relative to energy in the diet, which allows the animal to express its maximum potential for protein deposition. These subjects are of great interest for calculating energy and protein requirements at each stage of growth, designing feed formulation and planning optimal feeding strategies, on the one hand, and for commercial evaluation and carcass grading, on the other.

Material and methods

The experimental protocol for each set of trials involved in this analysis was approved by the Bioethical Committee of the Spanish Council for Scientific Research (Madrid, Spain).

Animals, feed, and experimental design

In this study an evaluation is made of the changes observed in the composition of EBG and of the rate of growth of main body components of 211 growing-finishing IB pigs from four independent experiments. Ninety-nine of these pigs received an adequate dietary treatment, *i.e.*, an optimal or sub-optimal supply of AA relative to energy in their diet (leading to no differences in whole-body protein deposition when offered at the same feeding level). The pigs used in the experiments were described by Nieto *et al.* (2002a), Barea *et al.* (2007), García-Valverde *et al.* (2008), and Conde-Aguilera *et al.* (2011a). Protein- and fat deposition rates are reported there. The range of corresponding body weight (BW) was 15-50, 50-100, 100-150, or 10-25 kg for those experiments, respectively. Data on carcass composition, carcass traits and primal cuts at these BW ranges have been published elsewhere (Nieto *et al.*, 2003; Barea *et al.*, 2006; García-Valverde *et al.*, 2008; Conde-Aguilera *et al.*, 2011b). All pigs were purebred castrated boars of the Silvela strain supplied by a single breeding company (Sánchez Romero Carvajal Jaugo S.A., El Puerto de Santa María, Cádiz, Spain).

A description of management protocol, experimental treatments, slaughter methods, and chemical analysis procedures has been reported by Nieto *et al.* (2012).

Briefly, the pigs were fed restrictively a common diet during the growing phase until they reached their target weight. Then, they were moved into individual pens and randomly assigned to the experimental treatments. Within each experiment, several concentrations of dietary ideal protein, expressed as the ratio of apparent digestible protein to metabolizable energy (ApDP:ME, g MJ⁻¹), and two or three levels of feed intake, expressed in terms of the ad libitum intake (*i.e.*, times ad libitum), were used in a factorial arrangement of treatments (Table 1). The greatest level of feeding was fixed as 0.95 × ad libitum. A brief description of the procedure followed to estimate ad libitum intake has been described by Nieto *et al.* (2012). Within each experiment, the experimental diets were prepared by diluting a high-protein diet, formulated to provide an optimum pattern of AA, with a protein-free mixture made to match the macronutrient content of the high-protein diet. Dietary crude protein [CP, g kg⁻¹ dry matter (DM)], Lysine (Lys, g kg⁻¹ DM) and ME (MJ kg⁻¹ DM) contents, respectively, were in the range of 101 to 223, 7.32 to 16.16 and 14.6 to 15.5 (Nieto *et al.*, 2002a), 123 to 201, 8.90 to 14.54 and 14.6 to 14.7 (Conde-Aguilera *et al.*, 2011a), and 70 to 145, 4.77 to 9.89 and 13.9 to 14.8 (Barea *et al.*, 2007). In the study by García-Valverde *et al.* (2008), a single level of ideal protein was assayed (95 g kg⁻¹ DM; 7.09 g Lys kg⁻¹ DM), and the experimental diet contained 14.8 MJ kg⁻¹ DM of ME.

Experimental procedure

During the experiments, the daily feed allowance was adjusted weekly based on the BW of the pigs measured individually before feeding. Water was freely available. Classical digestibility and balance trials were conducted towards the middle of the experimental period.

The comparative slaughter procedure was used to determine body composition, protein and fat accretion, and energy retention. The total body composition of the pigs in the experimental groups at the start of the trials was estimated from the chemical composition of an additional group of pigs slaughtered at the beginning of the experiment. For this purpose, the mean relationship between BW and empty-body weight (EBW) at slaughter (obtained by adding all the body components collected) was determined and applied together with the analytical data of the initial group. Total body

Table 1. The effects of protein content of the diet and feeding level on the chemical composition of empty-body gain (EBG) of Iberian pigs slaughtered at different body weight (BW)

BW (kg)	n	Slaughter weight (kg)	Empty-body weight (kg)	Dietary treatment	EBG (g d ⁻¹)	Protein (g kg ⁻¹)	Fat (g kg ⁻¹)	Ash (g kg ⁻¹)	Water (g kg ⁻¹)	Energy (MJ kg ⁻¹)	Reference ^a																			
10-25	48	25.2±0.1	23.4±0.1	ApDP:ME ^b (g MJ ⁻¹)							Conde-Aguilera <i>et al.</i> (2011b)																			
												10.87 ^c	329	157	178	31.3	627	10.83												
												9.20 ^c	325	149	189	31.9	623	11.09												
												7.86	299	139	239	28.8	586	12.82												
												5.96	283	128	278	28.7	552	14.12												
												SE	7	2	8	1.3	7	0.28												
												Feeding level ^d																		
												0.70	251	149	217	32.7	592	12.16												
												0.95	367	138	226	27.6	602	12.26												
												SE	5	2	6	0.9	5	0.20												
												15-50	71	49.9±0.3	48.3±0.3	ApDP:ME (g MJ ⁻¹)							Nieto <i>et al.</i> (2003)							
																								12.19	394	120	398	27.2	441	18.70
																								10.83	356	134	381	33.7	455	18.33
																								9.63	374	132	395	32.2	445	18.85
8.24 ^c	403	132	400	29.4	436	19.04																								
6.86 ^c	440	130	419	26.0	421	19.76																								
5.16	419	125	422	28.2	424	19.75																								
SE	11	2	10	1.5	9	0.28																								
Feeding level																														
0.60	281	131	401	29.4	432	19.07																								
0.80	411	125	413	29.7	429	19.41																								
0.95	502	131	393	29.3	451	18.74																								
SE	8	2	8	1.1	7	0.28																								
50-100	81	99.5±0.2	97.0±0.2	ApDP:ME (g MJ ⁻¹)							Barea <i>et al.</i> (2006)																			
												8.05	597	83	589	34.0	295	25.38												
												6.53 ^c	644	79	583	28.2	306	25.03												
												5.17 ^c	673	79	599	29.0	287	25.70												
												3.68	651	72	634	25.6	263	26.90												
												SE	9	3	11	1.8	9	0.38												
												Feeding level																		
												0.60	476	87	583	32.4	295	25.20												
												0.80	659	73	610	26.2	285	25.99												
												0.95	790	74	611	28.9	283	26.07												
												SE	9	3	9	1.5	8	0.33												
												100-150	11	149.5±1.3	144.4±1.0	ApDP:ME (g MJ ⁻¹)							García-Valverde <i>et al.</i> (2008)							
																								4.82 ^c						
																								Feeding level						
0.70	662	116	588	21.0	275	26.07																								
0.95	885	95	582	16.3	307	25.30																								
SE	33	6	52	2.7	35	0.48																								

^a Taken from the experiments by Conde-Aguilera *et al.* (2011b), following a 4 (dietary protein content) × 2 [feeding level (FL)] factorial arrangement with 6 individually housed piglets per combination of treatments; Nieto *et al.* (2003), according to a 6 (dietary protein content) × 3 FL factorial arrangement with 4 individually housed piglets per combination of treatments; Barea *et al.* (2006), following a 4 (dietary protein content) × 3 FL factorial arrangement with 6 to 7 individually housed pigs per combination of treatments; and García-Valverde *et al.* (2008), with 5 to 6 pigs per FL. ^b ApDP:ME = Apparent digestible protein to ME ratio. ^c Balanced or suboptimum protein-to-energy diet. ^d Times voluntary intake.

composition was calculated from the chemical composition of four body components [(i) carcass (including skin and hair), (ii) head plus feet and tail, (iii) viscera, and (iv) blood] and their respective weights. Increases in protein, energy, fat, and ash were then calculated as the difference between the final measured composition of the experimental pigs and the estimated initial composition, assessed from the initial group. For this purpose, separate aliquots of freeze-dried material were analysed for DM content, crude protein (CP; total N \times 6.25), and ash according to AOAC procedures (AOAC, 1990). The gross energy (GE) of freeze-dried samples (placed in polyethylene bags of known GE value) was measured with an adiabatic or isoperibolic bomb calorimeter. Body fat was calculated assuming energy contents of 23.85 and 39.75 kJ g⁻¹ for protein and fat, respectively (Wenk *et al.*, 2001).

Procedures followed for carcass fabrication have been described by Nieto *et al.* (2013). Briefly, the shoulder was separated from the loin and belly by a straight cut between the second and third ribs and a straight cut 2.5 cm ventral to the ventral edge of the scapula. The ham was removed from the loin by a straight cut between the second and third sacral vertebrae approximately perpendicular to the shank bones. Each cut retained its corresponding skin and subcutaneous fat. The loin was separated from the belly by a cut beginning just ventral to the ventral side of the scapula at the cranial end and followed the natural curvature of the vertebral column to the ventral edge of the *psoas major* at the caudal end of the loin. Each cut was weighed. After weighing, trimmed hams and shoulders were obtained by eliminating part of the external fat and skin using a knife to comply with the commercial requirements. Thereafter, trimmed shoulders and hams were physically dissected into skin, external adipose tissue (subcutaneous fat), intermuscular adipose tissue (intermuscular fat), muscle (including blood vessels, ligaments, tendons and connective tissue) and bone. The weight of each dissected component was recorded.

Statistical analyses

The SAS software (SAS Inst. Inc., Cary, NC) was used for all statistical analyses. The individual pig was considered as the experimental unit. To predict body protein accretion and calculate the net efficiency of utilization of dietary protein in the growing pig offered diets that provided adequate ideal protein to energy

ratios, N retention (NR, mg kg⁻¹ BW^{0.75} d⁻¹) was related to N intake (NI, mg kg⁻¹ BW^{0.75} d⁻¹) or to the intake of N apparently absorbed (NdigAp, mg kg⁻¹ BW^{0.75} d⁻¹) by means of linear regression equations. A multiple regression equation was also derived that describes quantitatively the effects of protein- and energy supply, and of BW, on the efficiency with which dietary N provided over maintenance is deposited in the body of these pigs. Means of EBG, physical and chemical body components and their SE were calculated for each stage of growth or BW pig group. All regression equations were obtained by the PROC NLIN of SAS. The EBW was estimated from BW by an allometric function of BW. Multiple regression equations were calculated with data obtained from pigs fed adequate protein-to-energy diets to predict average daily gain (ADG) and EBG at each stage of growth from average BW and level of feeding expressed as a multiple of the energy requirements for maintenance (ME_m). For this purpose, values of ME_m estimated at each BW range were used. Also, using all dietary treatments, a multiple regression equation was obtained to estimate EBG from mass of protein and fat daily deposited. Multiple-regression equations were calculated following a stepwise forward procedure to estimate the nutrient (g kg⁻¹) and energy (MJ kg⁻¹) composition of EBG of pigs as a function of EBW, dietary protein to energy ratio, and feeding level. Partial F-tests were made to ascertain the statistical significance of the regression terms and removed those with $p > 0.05$. Several equations were also fitted to the data to analyse the relationship between the weight of a primal cut (g) in the carcass of the growing pig, on the one hand, and the EBW (kg) and the nutritional factors studied, on the other. The R^2 and the residual standard deviation (RSD) were used as measures of goodness of fit. The stepwise procedure described above was also used to calculate multiple regressions to estimate the weight of tissue components in trimmed shoulders and hams as a function of EBW of pigs, dietary protein to energy ratio, and feeding level. Partial F-tests were also made to ascertain the statistical significance of the regression terms, removing those with $p > 0.05$. The R^2 and RSD were used as measures of goodness of fit.

Results

The mean weights and EBW of the IB pigs at slaughter are shown in Table 1. In pigs from 10 to 150 kg BW,

which received adequate protein-to-energy dietary treatments, EBW (kg) was closely correlated with BW (kg) and could be accurately predicted by the following highly significant ($p < 0.001$) allometric equation:

$$\text{EBW} = 0.940 \pm 0.014 \times \text{BW}^{1.007 \pm 0.003} \quad [1]$$

(n = 99; $R^2 = 0.999$; RSD = 1.03)

In these pigs, at each stage of production, ADG (g) and EBG (g d⁻¹) were predicted as a function of the average BW and level of feeding, expressed as a multiple of ME_m (ME intake:ME_m), by the following regression equations ($p < 0.001$):

$$\text{ADG} = -286 \pm 26.7 + 3.44 \pm 0.168 \times \text{BW} + 185 \pm 8.0 \times \text{ME intake:ME}_m \quad [2]$$

(n = 99; $R^2 = 0.936$; RSD = 52.5)

$$\text{EBG} = -283 \pm 24 + 3.18 \pm 0.15 \times \text{BW} + 185 \pm 7 \times \text{ME intake:ME}_m \quad [3]$$

(n = 99; $R^2 = 0.942$; RSD = 48.0)

It was found that EBG increased in 4.69 g g⁻¹ of protein accreted (indicating that each g of protein accreted is associated to 3.69 g of water) and 1.024 g g⁻¹ of fat deposited, as shown by the following equation:

$$\text{EBG} = 4.69 \pm 0.10 \times \text{protein deposited} + 1.024 \pm 0.019 \times \text{fat deposited} \quad [4]$$

(n = 211; $R^2 = 0.994$; RSD = 40.2)

In the IB pigs fed adequate protein-to-energy diets, N retention (as an index of protein gain, highly correlated to EBG, as shown by Eq. [4]) can be estimated from N intake by the following highly significant linear regression equation ($p < 0.001$):

$$\text{NR, mg kg}^{-1} \text{ BW}^{0.75} \text{ d}^{-1} = -99 \pm 53 + 0.290 \pm 0.025 \times \text{NI, mg kg}^{-1} \text{ BW}^{0.75} \text{ d}^{-1} \quad [5]$$

(n = 99; $R^2 = 0.57$; RSD = 129)

Equation [5] estimates total endogenous N losses (N_{end}) as 99 mg kg⁻¹ BW^{0.75} d⁻¹ and N requirements for maintenance (N_m) as 341 (99/0.290) mg kg⁻¹ BW^{0.75} d⁻¹. As the average daily dry matter intake (DMI) was 1.949 kg, these N_{end} losses result in 51 mg/(kg BW^{0.75} × kg DMI) d⁻¹.

In the growing IB pig provided adequate protein-to-energy ratios, the dietary N apparently digested in the total tract (ApDN) was estimated to be used both for maintenance and production purposes with a net efficiency of 0.386 ± 0.031, as stated by the following regression ($p < 0.001$):

$$\text{NR, mg kg}^{-1} \text{ BW}^{0.75} \text{ d}^{-1} = -115 \pm 51 + 0.386 \pm 0.031 \times \text{ApDN, mg kg}^{-1} \text{ BW}^{0.75} \text{ d}^{-1} \quad [6]$$

(n = 99; $R^2 = 0.60$; RSD = 128)

Table 1 also shows the overall mean values of the chemical composition (g kg⁻¹) of EBG of pigs slaughtered at various BW after consuming diets that differed in protein-to-energy ratio given at different feeding levels. On average, protein content in EBG ranged from 143 to 78 g kg⁻¹ and fat from 221 to 601 g kg⁻¹ as BW increased from 10 to 100 kg. The corresponding energy value of the EBG of the IB pig increased from 12.21 MJ kg⁻¹ to 25.75 MJ kg⁻¹. Water content changed concomitantly with protein content, ranging from 597 g kg⁻¹ in pigs of 10 to 25 kg BW to 288 g kg⁻¹ in the fattening pigs and ash content from 30.2 g kg⁻¹ at the earliest stage of growth to 29.2 g kg⁻¹. At the finishing stage, from 100 to 150 kg BW, average protein, fat, water and ash concentrations in EBG were 110, 585, 291 and 18.7 g kg⁻¹, while energy content remained at 25.69 MJ kg⁻¹ EBG.

Multiple regression equations were constructed to predict the chemical composition (g kg⁻¹) and energy content (MJ kg⁻¹) of the EBG of pigs growing from 10 to 150 kg BW as a function of EBW, ApDP:ME (g MJ⁻¹), and feeding level expressed as a multiple of ME_m (ME intake:ME_m), using for ME_m our preferred value of 413 kJ kg⁻¹ BW^{0.75} d⁻¹ (Nieto *et al.*, 2012). Best fits were obtained by the following equations ($p < 0.001$):

$$\text{Protein} = 182 \pm 9 - 1.78 \pm 0.15 \times \text{EBW} + 0.0085 \pm 0.0009 \times \text{EBW}^2 + 2.53 \pm 0.60 \times \text{ApDP:ME} - 5.25 \pm 1.76 \times \text{ME intake:ME}_m \quad [7]$$

(n = 211; $R^2 = 0.748$; RSD = 15.7)

$$\text{Fat} = 62 \pm 29 + 9.41 \pm 0.46 \times \text{EBW} - 0.0387 \pm 0.0029 \times \text{EBW}^2 - 7.3 \pm 1.9 \times \text{ApDP:ME} + 9.8 \pm 5.5 \times \text{ME intake:ME}_m \quad [8]$$

(n = 211; $R^2 = 0.907$; RSD = 49.5)

$$\text{Water} = 715 \pm 24 - 8.59 \pm 0.38 \times \text{EBW} + 0.038 \pm 0.002 \times \text{EBW}^2 + 5.3 \pm 1.6 \times \text{ApDP:ME} \quad [9]$$

(n = 211; $R^2 = 0.899$; RSD = 41.0)

$$\text{Ash} = 0.050 \pm 0.018 \times \text{EBW} + 2.18 \pm 0.19 \times \text{ApDP:ME} + 2.64 \pm 0.63 \times \text{ME intake:ME}_m \quad [10]$$

(n = 211; $R^2 = 0.933$; RSD = 7.79)

$$\text{Energy} = 7.54 \pm 0.88 + 0.338 \pm 0.016 \times \text{EBW} - 0.0014 \pm 0.0001 \times \text{EBW}^2 - 0.238 \pm 0.069 \times \text{ApDP:ME} \quad [11]$$

(n = 211; $R^2 = 0.899$; RSD = 1.84)

It was found that, as a percentage of EBW, the cold eviscerated carcass (CC; without the head, feet, and tail) of the growing IB pigs increased with EBW (Ta-

Table 2. Mean weights and yield of primal cuts in the half cold carcass of Iberian pigs slaughtered at different body weight (BW)^a

Item	BW (kg)							
	10-25		15-50		50-100		100-150	
	Weight (kg)	Yield ^b (%)	Weight (kg)	Yield (%)	Weight (kg)	Yield (%)	Weight (kg)	Yield (%)
<i>All dietary treatments (n = 211)</i>								
n	48		71		81		11	
Total BW	25.2±0.1	—	49.9±0.3	—	99.5±0.2	—	149.5±1.3	—
Empty BW ^c	23.4±0.1	92.9	48.3±0.3	96.8	97.0±0.2	97.5	144.4±1.0	96.6
Warm carcass ^d	18.7±0.1	79.9	40.6±0.3	84.0	84.8±0.3	87.4	126.7±1.1	87.7
Cold carcass ^e	15.5±0.1	66.2	35.8±0.2	74.1	75.9±0.2	78.3	114.2±1.0	79.1
Sirloin	0.057±0.002	0.750	0.111±0.002	0.628	0.174±0.003	0.470	0.266±0.009	0.480
Butt lean	0.325±0.010	4.29	0.859±0.017	4.84	1.447±0.018	3.90	1.746±0.068	3.14
Loin	0.351±0.010	4.63	0.821±0.012	4.62	1.224±0.022	3.30	1.550±0.072	2.79
Ribs	0.556±0.007	7.37	0.934±0.013	5.28	1.652±0.020	4.46	2.384±0.090	4.29
Spine	0.497±0.016	6.56	0.886±0.023	5.00	1.287±0.029	3.47	1.72±0.14	3.09
Backfat	0.272±0.006	3.60	1.019±0.024	5.72	3.47±0.06	9.34	5.43±0.21	9.76
Shoulder	1.90±0.02	25.1	4.51±0.04	25.5	8.18±0.07	22.0	13.1±0.3	23.6
Trimmed shoulder	1.47±0.01	19.5	3.02±0.02	17.0	5.06±0.05	13.6	8.49±0.19	15.3
Ham	2.52±0.02	33.3	5.31±0.05	29.9	10.11±0.05	27.3	14.9±0.2	26.7
Trimmed ham	2.17±0.02	28.7	4.21±0.04	23.7	7.23±0.05	19.5	11.5±0.2	20.7
Kidney fat	0.089±0.004	1.18	0.564±0.015	3.16	1.87±0.04	5.03	2.98±0.10	5.37
Belly	0.937±0.012	12.4	2.90±0.03	16.3	7.19±0.07	19.4	11.1±0.2	19.9
<i>Adequate protein-to-energy diets (n = 99)</i>								
n	24		24		40		11	
Total BW	25.2±0.1	—	50.8±0.5	—	99.5±0.4	—	149.5±1.3	—
Empty BW	23.4±0.1	92.6	49.3±0.5	97.0	96.9±0.3	97.4	144.5±1.0	96.7
Warm carcass	18.6±0.1	79.5	41.6±0.5	84.4	84.7±0.4	87.4	126.7±1.1	87.7
Cold carcass	15.4±0.1	65.8	36.5±0.4	74.0	75.8±0.3	78.2	114.2±1.0	79.0
Sirloin	0.061±0.002	0.814	0.114±0.004	0.632	0.176±0.004	0.480	0.266±0.009	0.480
Butt lean	0.317±0.013	4.22	0.874±0.025	4.88	1.436±0.026	3.87	1.746±0.068	3.14
Loin	0.356±0.012	4.76	0.842±0.019	4.68	1.211±0.038	3.27	1.550±0.072	2.79
Ribs	0.557±0.009	7.42	0.897±0.020	5.01	1.686±0.027	4.54	2.384±0.090	4.29
Spine	0.501±0.026	6.66	0.918±0.042	5.11	1.325±0.040	3.57	1.72±0.14	3.09
Backfat	0.257±0.009	3.43	1.051±0.040	5.84	3.43±0.09	9.24	5.43±0.21	9.76
Shoulder	1.86±0.02	24.9	4.53±0.06	25.3	8.21±0.08	22.1	13.1±0.3	23.6
Trimmed shoulder	1.48±0.01	19.7	3.09±0.04	17.2	5.11±0.07	13.8	8.49±0.19	15.3
Ham	2.53±0.02	33.8	5.39±0.09	29.9	10.16±0.07	27.4	14.9±0.2	26.7
Trimmed ham	2.20±0.02	29.3	4.26±0.09	23.7	7.27±0.07	19.6	11.5±0.2	20.7
Kidney fat	0.077±0.005	1.03	0.556±0.024	3.08	1.876±0.048	5.04	2.98±0.10	5.37
Belly	0.928±0.016	12.4	2.93±0.05	16.3	7.15±0.08	19.3	11.1±0.2	19.9

^a Taken from the experiments by Conde-Aguilera *et al.* (2011b), Nieto *et al.* (2003), Barea *et al.* (2006), and García-Valverde *et al.* (2008), in pigs growing from 10 to 25, 15 to 50, 50 to 100, and 100 to 150 kg BW, respectively. ^b Primal cut yield calculated as percentage of the dissected half-cold carcass weight. ^c Calculated as the sum of warm carcass, total viscera and organs, and blood. ^d Including head, feet, and tail. ^e Without head, feet, and tail.

ble 2). Differences in CC to EBW ratios with respect to pigs receiving adequate protein-to-energy diets were negligible. The growth pattern of the main primal cuts of the CC of pigs growing from 10 to 150 kg BW is also presented in Table 2. As proportions of CC weight, leaner cuts tended to decline with increasing

slaughter weight or CC weight, while the opposite was observed for fatter cuts. Several multiple regression equations were constructed to relate the total mass of a primal cut in half of the CC (g) of the growing pigs with the corresponding EBW, the protein to energy ratio in the diet, and the level of feeding. Best fit equa-

Table 3. Multiple regression equations relating the weight of a primal cut (g) in half of the cold carcass to empty body weight (EBW, kg), dietary protein to energy ratio (ApDP:ME, g MJ⁻¹)^a, and feeding level (ME intake:ME_m)^b

Item	Equation	R ²	RSD ^c
<i>All dietary treatments (n = 211)</i>			
Sirloin	$1.670 \pm 0.031 \times \text{EBW} + 2.77 \pm 0.30 \times (\text{ApDP:ME})$	0.977	22.1
Butt lean	$12.72 \pm 0.36 \times \text{EBW} + 47.7 \pm 7.7 \times (\text{ME intake:ME}_m)$	0.997	169
Loin	$11.43 \pm 0.21 \times \text{EBW} + 20.7 \pm 2.0 \times (\text{ApDP:ME})$	0.978	149
Ribs	$15.83 \pm 0.21 \times \text{EBW} + 19.9 \pm 2.0 \times (\text{ApDP:ME})$	0.988	146
Spine	$9.63 \pm 0.51 \times \text{EBW} + 100.9 \pm 10.8 \times (\text{ME intake:ME}_m)$	0.952	238
Backfat	$42.51 \pm 1.00 \times \text{EBW} - 56.3 \pm 10.4 \times (\text{ApDP:ME}) - 108 \pm 35 \times (\text{ME intake:ME}_m)$	0.973	429
Shoulder	$399 \pm 187 + 86.81 \pm 1.13 \times \text{EBW} - 109 \pm 57 \times (\text{ME intake:ME}_m)$	0.970	531
Trimmed shoulder	$584 \pm 213 + 53.83 \pm 1.00 \times \text{EBW} + 34 \pm 15 \times (\text{ApDP:ME}) - 193 \pm 42 \times (\text{ME intake:ME}_m)$	0.956	385
Ham	$662 \pm 110 + 102.94 \pm 0.66 \times \text{EBW} - 134 \pm 33 \times (\text{ME intake:ME}_m)$	0.992	311
Trimmed ham	$1,172 \pm 215 + 74.14 \pm 1.02 \times \text{EBW} + 27 \pm 15 \times (\text{ApDP:ME}) - 287 \pm 42 \times (\text{ME intake:ME}_m)$	0.976	390
Kidney fat	$-226 \pm 24 + 3.06 \pm 0.11 \times \text{EBW} - 5.73 \pm 1.63 \times (\text{ApDP:ME}) + 89.2 \pm 4.7 \times (\text{ME intake:ME}_m)$	0.925	42.9
Belly	$79.65 \pm 0.67 \times \text{EBW} - 98.0 \pm 6.4 \times (\text{ApDP:ME})$	0.992	473
Main primal cuts ^d	$1,413 \pm 258 + 214.68 \pm 1.56 \times \text{EBW} - 229 \pm 79 \times (\text{ME intake:ME}_m)$	0.990	732
<i>Adequate protein-to-energy diets (n = 99)</i>			
Sirloin	$51.0 \pm 10.8 + 1.67 \pm 0.06 \times \text{EBW} - 8.83 \pm 3.31 \times (\text{ME intake:ME}_m)$	0.905	20.8
Butt lean	$11.94 \pm 0.51 \times \text{EBW} + 58.3 \pm 11.9 \times (\text{ME intake:ME}_m)$	0.977	183
Loin	$10.09 \pm 0.59 \times \text{EBW} + 57.6 \pm 13.8 \times (\text{ME intake:ME}_m)$	0.959	213
Ribs	$15.34 \pm 0.43 \times \text{EBW} + 48.7 \pm 10.1 \times (\text{ME intake:ME}_m)$	0.989	155
Spine	$9.39 \pm 0.73 \times \text{EBW} + 111.9 \pm 16.9 \times (\text{ME intake:ME}_m)$	0.952	261
Backfat	$44.4 \pm 1.3 \times \text{EBW} - 256 \pm 31 \times (\text{ME intake:ME}_m)$	0.973	483
Shoulder	$89.8 \pm 1.5 \times \text{EBW} - 61 \pm 35 \times (\text{ME intake:ME}_m)$	0.995	536
Trimmed shoulder	$990 \pm 231 + 55.2 \pm 1.2 \times \text{EBW} - 256 \pm 71 \times (\text{ME intake:ME}_m)$	0.959	443
Ham	$102.5 \pm 1.0 \times \text{EBW} + 58 \pm 24 \times (\text{ME intake:ME}_m)$	0.998	371
Trimmed ham	$1,556 \pm 221 + 75.5 \pm 1.2 \times \text{EBW} - 362 \pm 68 \times (\text{ME intake:ME}_m)$	0.979	425
Kidney fat	$25.13 \pm 0.68 \times \text{EBW} - 163 \pm 16 \times (\text{ME intake:ME}_m)$	0.977	244
Belly	$84.4 \pm 1.4 \times \text{EBW} - 299 \pm 32 \times (\text{ME intake:ME}_m)$	0.994	490
Main primal cuts ^d	$1,207 \pm 328 + 204.2 \pm 1.8 \times \text{EBW} - 277 \pm 100 \times (\text{ME intake:ME}_m)$	0.994	630

^a Apparent digestible protein to ME ratio. ^b Intake of ME expressed as a multiple of ME for maintenance. ^c RSD: residual standard deviation. ^d Calculated as the sum of sirloin, loin, shoulder, and ham.

tions are shown in Table 3. Best fit multiple regression equations are shown in Table 4, derived to relate the weight of dissectible tissues in the trimmed shoulder and ham (g) with EBW, the protein to energy ratio in the diet, and the feeding level.

Discussion

A main goal of pig production is to control animal growth, *i.e.*, the rate and composition of gain, and to improve the efficiency of the productive process. We have recently demonstrated that the growth of body components, the total whole-body chemical composition and the relative growth of tissues in the carcass of the IB pig do not adjust to growth models published for lean and conventional genotypes, implying sub-

stantial differences in nutrient requirements (Nieto *et al.*, 2012, 2013). Furthermore, when the response of the IB pig at various stages of growth to changes in energy supply at different ideal protein concentrations was analysed, it was also found that energy intake was a critical factor in the pig's response, as previously observed in pigs of lean or conventional breeds, but the utilization of energy for maintenance and productive processes clearly differed: (i) The meta-analysis of data from energy balance trials performed in purebred IB pigs from birth to 150 kg BW (Nieto *et al.*, 2012) allowed us to assume for ME_m the value of 413 kJ kg⁻¹ BW^{0.75} d⁻¹, which results in a different pattern of change of ME_m with BW and predicts clearly lower maintenance requirements for pigs below 100 kg BW than those that can be calculated from the standard value of 824 kJ kg⁻¹ BW^{0.60} d⁻¹, reported by NRC (2012), as a

Table 4. Multiple regression equations relating the weight of tissue components (g) in trimmed shoulders and hams of Iberian pigs slaughtered at different body weight (BW) to empty BW (EBW, kg), dietary protein to energy ratio (ApDP:ME, g MJ⁻¹)^a, and feeding level (ME intake:ME_m)^b

Item	Equation	R ²	RSD ^c
<i>All dietary treatments (n = 211)</i>			
Trimmed shoulder			
Skin	$2.482 \pm 0.069 \times \text{EBW} + 10.34 \pm 0.66 \times (\text{ApDP:ME})$	0.964	48.8
Subcutaneous fat (Sf)	$24.07 \pm 0.51 \times \text{EBW} - 59 \pm 18 \times (\text{ME intake:ME}_m) - 26.8 \pm 5.3 \times (\text{ApDP:ME})$	0.978	219
Intermuscular fat (If) ^d	$4.65 \pm 0.55 \times \text{EBW} - 93 \pm 23 \times (\text{ME intake:ME}_m) + 23.0 \pm 7.2 \times (\text{ApDP:ME})$	0.590	170
Sf + If ^d	$29.52 \pm 0.81 \times \text{EBW} - 150 \pm 18 \times (\text{ME intake:ME}_m)$	0.970	305
Muscle ^e	$527 \pm 155 + 18.97 \pm 0.73 \times \text{EBW} - 105 \pm 30 \times (\text{ME intake:ME}_m) + 34 \pm 11 \times (\text{ApDP:ME})$	0.818	279
Bone	$5.95 \pm 0.15 \times \text{EBW} + 17.5 \pm 5.3 \times (\text{ME intake:ME}_m) + 9.95 \pm 1.58 \times (\text{ApDP:ME})$	0.987	65.2
Trimmed ham			
Skin	$2.776 \pm 0.076 \times \text{EBW} + 11.68 \pm 0.73 \times (\text{ApDP:ME})$	0.965	53.7
Subcutaneous fat	$29.44 \pm 0.64 \times \text{EBW} - 105 \pm 22 \times (\text{ME intake:ME}_m) - 26.8 \pm 6.7 \times (\text{ApDP:ME})$	0.976	276
Intermuscular fat	$5.20 \pm 0.12 \times \text{EBW} - 9.73 \pm 1.12 \times (\text{ApDP:ME})$	0.943	82.4
Sf + If	$34.58 \pm 0.75 \times \text{EBW} - 103 \pm 26 \times (\text{ME intake:ME}_m) - 37.2 \pm 7.8 \times (\text{ApDP:ME})$	0.977	322
Muscle ^e	$773 \pm 194 + 29.57 \pm 0.91 \times \text{EBW} - 144 \pm 38 \times (\text{ME intake:ME}_m) + 50 \pm 13 \times (\text{ApDP:ME})$	0.877	349
Bone	$176 \pm 34 + 7.22 \pm 0.21 \times \text{EBW} + 6.5 \pm 3.1 \times (\text{ApDP:ME})$	0.898	81.7
<i>Adequate protein-to-energy diets (n = 99)</i>			
Trimmed shoulder			
Skin	$301 \pm 68 + 1.71 \pm 0.26 \times \text{EBW} - 21.4 \pm 8.1 \times (\text{ME intake:ME}_m) - 14.3 \pm 5.1 \times (\text{ApDP:ME})$	0.780	47.3
Subcutaneous fat	$-1,235 \pm 241 + 28.9 \pm 1.2 \times \text{EBW} + 70 \pm 22 \times (\text{ApDP:ME})$	0.954	222
Intermuscular fat ^d	$-1,420 \pm 184 + 9.68 \pm 0.92 \times \text{EBW} + 122 \pm 17 \times (\text{ApDP:ME})$	0.669	153
Sf + If ^d	$-2,820 \pm 313 + 39.9 \pm 1.6 \times \text{EBW} + 211 \pm 29 \times (\text{ApDP:ME})$	0.970	305
Muscle ^e	$2,286 \pm 350 + 13.3 \pm 1.3 \times \text{EBW} - 184 \pm 42 \times (\text{ME intake:ME}_m) - 116 \pm 26 \times (\text{ApDP:ME})$	0.891	244
Bone	$495 \pm 71 + 3.86 \pm 0.35 \times \text{EBW} - 30.1 \pm 6.5 \times (\text{ApDP:ME})$	0.912	65.2
Trimmed ham			
Skin	$365 \pm 65 + 1.60 \pm 0.25 \times \text{EBW} - 17.0 \pm 7.8 \times (\text{ME intake:ME}_m) - 19.8 \pm 4.9 \times (\text{ApDP:ME})$	0.818	45.6
Subcutaneous fat	$-1,201 \pm 460 + 36.4 \pm 1.7 \times \text{EBW} - 133 \pm 55 \times (\text{ME intake:ME}_m) + 89 \pm 35 \times (\text{ApDP:ME})$	0.937	321
Intermuscular fat	$-354 \pm 87 + 6.90 \pm 0.43 \times \text{EBW} + 24.5 \pm 8.1 \times (\text{ApDP:ME})$	0.889	80.5
Sf + If	$-2,280 \pm 396 + 43.8 \pm 2.0 \times \text{EBW} + 144 \pm 37 \times (\text{ApDP:ME})$	0.941	365
Muscle ^e	$2,961 \pm 447 + 21.6 \pm 1.68 \times \text{EBW} - 229 \pm 53 \times (\text{ME intake:ME}_m) - 135 \pm 34 \times (\text{ApDP:ME})$	0.918	312
Bone	$665 \pm 93 + 4.88 \pm 0.46 \times \text{EBW} - 39.2 \pm 8.6 \times (\text{ApDP:ME})$	0.906	86.0

^a Apparent digestible protein to ME ratio. ^b Intake of ME expressed as a multiple of ME for maintenance. ^c RSD : residual standard deviation. ^d Intermuscular fat was obtained by dissection of only 120 shoulders, 66 of them from pigs on adequate protein-to-energy diets. ^e Including blood vessels, ligaments, tendons and connective tissue.

mean of published predictive equations ranging from 799 to 904 kJ kg⁻¹ BW^{0.60} d⁻¹ (Birkett & de Lange, 2001); and (ii) it was also found that the partial efficiencies of ME utilization for protein deposition (k_p) and fat deposition (k_f), calculated by means of a multiple regression equation with data from all these balance trials, were 0.397 and 0.641, respectively, and therefore, also less than those of 0.54 and 0.76, which can be calculated from the preferred estimates of energy costs for protein and fat deposition published by NRC (2012). Then, we assumed that k_p and k_f were fixed values, independent of BW and age, equiva-

lent to ME costs for protein and fat deposition of 60 and 62 kJ g⁻¹, respectively. Our results support the evidence of a genotype effect on the efficiency of energy utilization.

A main purpose of these studies was to derive the optimum protein (Lys) to energy ratio in the diet to allow the pig express maximum protein deposition rates. In this context, the exam and analytical treatment of the data on protein deposition (PD) from these trials revealed that in the IB pig maximum potential for protein deposition (PD_{max}, g d⁻¹) and marginal efficiency for protein deposition ($\Delta\text{PD}/\Delta\text{ME}$, g MJ⁻¹) differ wi-

dely from values observed in lean pig breeds (Nieto *et al.*, 2012). PD_{max} increases sharply during the earlier stage of growth, with a break point at ~ 32.5 kg BW, to remain at an average 75 g d^{-1} thereafter, and $\Delta PD/\Delta ME$ decreases from 4.39 g MJ^{-1} of ME in growing piglets to approach zero in the heavy pig. Best estimates of these parameters are obtained from an inverse regression and a logarithmic equation, respectively, relating them to BW (Nieto *et al.*, 2012). Consequently, PD_{max} is far less in the IB pig than in lean and conventional genotypes, irrespective of BW range ($>150 \text{ g d}^{-1}$; Quiniou *et al.*, 1996). Also, in IB pigs fed on optimum or sub-optimum protein to energy diets, the relationship between PD and ME intake declines, following a curvilinear pattern with increasing BW, thus implying relative increases in lipid gain with BW. Furthermore, the estimations made on the maintenance component of AA needs of IB pigs are in line with those reported by NRC (2012) as far as endogenous losses is concerned: In IB pigs of 110 kg BW fed two protein-free diets that differed in lignocellulose content, an average endogenous flow at distal ileum of $571 \text{ mg Lys kg}^{-1} \text{ DMI}$ and $2.91 \text{ g total N kg}^{-1} \text{ DMI}$ was observed (Nieto *et al.*, 2002b), implying an average Lys content of $31.4 \text{ mg Lys g}^{-1}$ endogenous protein, similar to that of $29.7 \text{ mg Lys g}^{-1}$ endogenous protein that can be calculated from NRC (2012) data. From these observations average endogenous losses of 16.8 and $86 \text{ mg}/(\text{kg BW}^{0.75} \text{ kg DMI}) \text{ d}^{-1}$, respectively for Lys and total N, can be calculated. These figures would correspondingly rise to 18.5 and $94 \text{ mg}/(\text{kg BW}^{0.75} \text{ kg DMI}) \text{ d}^{-1}$, when an increase of 10% of basal ileal endogenous losses is assumed for the contribution of hind gut to total intestinal tract losses (Moughan, 1999). However, the regression approach applied to the N balance data derived from the comparative slaughter procedure, reported by Nieto *et al.* (2002a), Barea *et al.* (2007), García-Valverde *et al.* (2008), and Conde-Aguilera *et al.* (2011a), indicated a total endogenous N loss of only $99 \text{ mg kg}^{-1} \text{ BW}^{0.75} \text{ d}^{-1}$ (Eq. [5]), equivalent to $51 \text{ mg N}/(\text{kg BW}^{0.7} \times \text{kg DMI}) \text{ d}^{-1}$ [$0.32 \text{ g CP} / (\text{kg BW}^{0.75} \times \text{kg DMI}) \text{ d}^{-1}$; $10 \text{ mg Lys} / (\text{kg BW}^{0.75} \times \text{kg DMI}) \text{ d}^{-1}$], assuming the observed average content of $31.4 \text{ mg Lys g}^{-1}$ endogenous protein at ileal level (Nieto *et al.*, 2002b)]. The IB pigs were at different stages of growth and had been offered optimum or sub-optimum protein to energy diets at several feeding levels (0.60 to $0.95 \times ad libitum$ intake). The coefficient of the independent term of Eq. [5] indicates that the ideal protein in the diet is used with an average efficiency of 0.290 ± 0.025 for

the combined processes of maintenance and protein accretion, and therefore N requirements for maintenance can be estimated as $99/0.290 = 341 \text{ mg kg}^{-1} \text{ BW}^{0.75} \text{ d}^{-1}$, equivalent to $175 \text{ mg}/(\text{kg BW}^{0.75} \times \text{kg DMI}) \text{ d}^{-1}$. In our experiments, the average coefficient of total tract apparent digestibility of the dietary protein—which was formulated in all trials according to the ideal AA profile and a content of 70 g Lys kg^{-1} (NRC, 1998; BSAS, 2003)—was 0.78 ± 0.05 ($n = 99$). Consequently, we assume that the N_m value of $175 \text{ mg}/(\text{kg BW}^{0.75} \times \text{kg DMI}) \text{ d}^{-1}$ or $1.09 \text{ g ideal CP}/(\text{kg BW}^{0.75} \times \text{kg DMI}) \text{ d}^{-1}$ can be converted into 0.85 (1.09×0.78) g apparent digestible protein (ApDP)/($\text{kg BW}^{0.75} \times \text{kg DMI}) \text{ d}^{-1}$; 63 (1.09×58) mg Lys/($\text{kg BW}^{0.75} \times \text{kg DMI}) \text{ d}^{-1}$ —taking a Lys content of 58 mg g^{-1} maintenance protein (BSAS, 2003)—or 49 (63×0.78) mg apparent digestible Lys (ApDLys)/($\text{kg BW}^{0.75} \times \text{kg DMI}) \text{ d}^{-1}$. Finally, for these IB pigs—growing from 10 to 150 kg BW under optimum or sub-optimum protein to energy diets offered at several feeding levels—, calculated requirements for protein accretion up to the pig's maximal capacity are based on: (i) a net efficiency of utilization of total tract apparent digestible ideal protein for protein deposition of 0.386 ± 0.031 (Eq. [6]); (ii) a concentration of 70 g Lys kg^{-1} body protein accreted, the average value from slaughter experiments reported by Kyriazakis *et al.* (1993), Bikker *et al.* (1994) and Mahan & Shield (1998), and (iii) the balance of dietary amino acids (g kg^{-1} protein) recommended by NRC (1998) and BSAS (2003). As calculations derived from Eqs. [5] and [6] are based on a considerable number of individual measurements of N balance from slaughter trials, they are our preferred estimations. Linearity of response in protein deposition to crude protein- or digestible protein intake when energy supply is not limiting at a wide range of BW has been widely recognized (Campbell *et al.*, 1984, 1985; Susenbeth, 1995; Dourmad *et al.*, 1996; Mohn *et al.*, 2000). Based on the analysis of the experimental results of 22 publications, Susenbeth (1995) concluded that “protein retention is determined solely by lysine intake, when it is the limiting factor. This means that a given lysine intake leads to the same protein retention independent of age, body weight, breed, sex and energy intake”. However, we have observed a significant lowering effect of BW on the efficiency with which dietary N supplied above maintenance requirements (NI_{prod}) is retained in the body of the pig, as depicted by the multiple regression equation ($p < 0.001$):

$$\begin{aligned} \text{NR}/\text{NI}_{\text{prod}} = & 0.533 \pm 0.050 - 0.119 \pm 0.027 \times \text{NI}, \\ & \text{g kg}^{-1} \text{BW}^{0.75} - 0.0080 \pm 0.0014 \times \text{kg BW}^{0.75} + \\ & + 0.00011 \pm 0.00004 \text{ IEM, kJ kg}^{-1} \text{BW}^{0.75} \quad [12] \\ & (\text{n} = 99; R^2 = 0.28; \text{RSD} = 0.07) \end{aligned}$$

where $\text{BWkg}^{0.75}$ indicates the average metabolic weight of each pig at the stage of growth at which N balance measurements took place (see Table 1). The low R^2 value suggests that other unknown factors affect this efficiency. These results are in line with observations reported by other authors (Black *et al.*, 1986; Bikker, 1994).

The effect of genotype and sex on the efficiency of protein utilization is a matter not yet fully clarified. It seems to increase slightly with improvement in genetic potential for lean tissue deposition (Mohn *et al.*, 2000; NRC, 2012). Kyriazakis *et al.* (1995) observed the same net efficiency in entire male Large White \times Landrace and pure Chinese Meishan pigs. Fuller *et al.* (1995) used Duroc, purebred Large White and a commercial hybrid. The re-examination of their data reveals that below PD_{max} the regression line has a common slope, indicating equal efficiency at sub-optimal intakes (Sandberg *et al.*, 2005). However, the lower value of the slope of Eqs. [5] and [6] suggests that compared with conventional or improved genotypes in the IB pig the change in body protein accretion per unit of change in protein intake is a more inefficient process.

To obtain robust estimations of the energy and AA needs of the IB pig growing from 10 to 150 kg BW, in the present paper a report is provided on specific relationships constructed to predict relative growth of body components and accurate estimations of whole body protein and lipid deposition from dietary protein and energy supply. In our studies, two sources of variation were considered: (i) the ideal dietary protein to energy ratio, and (ii) the level of feeding, the latter being of particular importance in practice, as high levels of feed restriction are applied to achieve quality standards in the dry-cured products from the IB pig. In Eqs. [7] to [11] the effects of the nutritional factors on the chemical composition of EBG are differentiated from the effect of EBW. Both the chemical composition of EBG and its energy content were sensitive to relative changes in dietary supply of protein and energy, while the level of feeding was the most important determinant of protein and fat content of gain, as is corroborated by the comparatively higher coefficient of the ME intake: ME_m term in the multiple re-

gression Eqs. [7] and [8]. Additionally, from Eq. [3], a decrease of 185 g in EBG can be predicted from each unit of reduction in ME intake: ME_m ratio. These equations match those constructed to predict changes in the chemical composition of EBW (Nieto *et al.*, 2012). From Eqs. [3], [7] and [8] the total mass (g) of protein and fat daily deposited in the body of the growing IB pig as a result of the provision of a specific dietary regimen can be accurately predicted. Then, to derive an accurate estimation of the energy and protein (Lys) requirements is a straight forward matter.

The IB is a slow-growing, obese breed of pigs. The production of dry-cured meat products is the main goal of the IB pig industry. To obtain the highest organoleptic quality products the management system must include a final fattening free-range stage based on acorn (*Quercus* spp.) and pasture, the former seasonally available (from mid-October to the end of February). In a classical production system, farrowing is scheduled at 3-month intervals with two reproductive cycles per sow and year. The weaned pig is fed at a growth rate which must allow the access to the final extensive period at 92 to 115 kg BW to attain at least 46 kg of total BW gain in a minimum of 60 days (Spanish Ministry of Agriculture guidelines; BOE, 2014). Slaughter takes place at a minimum age of 14 months. In practice, the range of ages of pigs with free access to acorn and pasture is highly variable, from 12 to 17 months. This implies a wide variation in feeding level, during the stages of growth preceding the phase of extensive production. Nevertheless, because of constraints imposed by the limited availability of natural resources, only about one fifth of IB pigs undergo the final fattening stage in free-range conditions. They are instead raised intensively with commercial feed either outdoors or confined and slaughtered at 10 to 12 months of age with a minimum carcass weight of 108 kg (115 kg for Duroc \times Iberian crossbred pigs). A significant part of this production is sent to market as fresh pork. From above it is obvious that the nutritional management of the IB pig should be planned to benefit of the maximal potential for protein accretion (that the pig shows at the earlier stages of growth) and of its capacity to attain high intramuscular fat and myoglobin contents throughout an extended productive cycle. An examination of data shown in Table 1 reveals that a substantial decrease in the relative proportion of protein and water in EBG concomitant with an enhanced fat deposition occurs on increasing BW, in agreement with the pattern of chemical changes ob-

served in the empty body (Nieto *et al.*, 2012) and CC (Nieto *et al.*, 2013) of these pigs.

A second objective of this study was to derive simple equations for accurate estimations of the size of primal cuts and of dissected tissues in the trimmed shoulder and ham from dietary protein and energy supply, a matter of particular relevance for the IB pig industry. As the pig grows, a decrease in the proportion of weight of primal cuts can be noticed concomitantly with the chemical changes observed, despite they increase their mass, as appears in Table 2. This decline is also the result of the diluting effect caused by the enhanced deposition of fat tissues (backfat, kidney fat). As reported by Nieto *et al.* (2013), in the IB pigs, the most relevant differences in pattern of developmental growth respect to lean and conventional pig breeds concern the comparatively smaller size of lean tissues, their lower rates of growth, and the increased total body fat content, with marked changes in its distribution among depots. Consequently, specific predictive equations are required. It must be emphasised that predictive equations of growth of physical components usually rely on measured changes in chemical body composition, mostly linked to genotype (Gu *et al.*, 1992; Quiniou & Noblet, 1995; Wagner *et al.*, 1999; de Lange *et al.*, 2003; Wiseman *et al.*, 2007, among others). However, in the case of IB pig, predictive equations may be of a greater value if they estimate the impact of nutritional strategies on carcass quality, because of their potential implications in the evaluation of end products for commercial purposes, particularly those of the dry-curing industry. Daza *et al.* (2007) obtained equations to predict the weight of major cuts in the carcass of IB pigs slaughtered after a free-range stage, based on slaughter weight or carcass weight. Noticeably, in the multiple regression equations shown in Tables 3 and 4, the effect of EBW on the total mass of primal cuts (Table 3) and on the mass of dissected tissues (Table 4), judged by the corresponding coefficient, was comparatively lower than those of the nutritional factors. Negligible differences in accuracy were found between estimations from equations derived from data taken from pigs on all dietary treatments and those constructed with data from pigs fed adequate protein-to-energy diets.

In conclusion, specific relationships have been constructed, which describe the partition of dietary protein in the body of the IB pig, and predict the chemical composition of gain, weight of primal cuts in the carcass of the IB pig, and mass of dissected tissues in trimmed

shoulders and hams from BW and nutrient supply. These relationships, which are not applicable to pigs of lean and conventional genotypes, can contribute to the design of optimal feeding strategies to improve the efficiency of IB pig production systems and to achieve high quality standards in end products.

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