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PAPER

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Growth performance, carcass traits and meat quality of growing pigs on different feeding regimes slaughtered at 145 kg BW

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ABSTRACT

This study investigated the effects of feeding regime on growth performance, carcass traits and meat quality of pigs slaughtered at around 145 kg BW. A total of 96 barrows housed in eight pens were allotted to three groups in each pen. One group was fed *ad libitum* (AL) and the others were fed according to two quasi AL feeding regimes adjusting feed allowances with increasing BW. At slaughterhouse, the weights of the main lean and fat cuts were recorded, and a sample of *longissimus lumborum* (LL) was taken for physical and chemical analyses. Average daily gain (ADG) approached 940 g d^{-1}, and gain to feed ratio (G:F) was close to 0.38. Compared with the AL-feeding regime, the feed restriction reduced the pigs' ADG (−3.5%), feed intake (−7.4%) and carcass weight (−3%) ($p < 0.01$), but improved their G:F (+4%, $p < 0.01$). Feeding regime did not affect meat quality traits and exerted only minor effects on the weight of primal cuts and on the fatty acid composition of the intramuscular fat of the LL. However, AL-fed pigs tended to yield heavier fat cuts and showed a greater proportion of saturated fatty acid in the LL when compared to restricted feed barrows. In conclusion, moderate restriction in the feeding of medium–heavy pigs seems advisable, as it improves feed efficiency and could cut feed costs compared with the AL-feeding regime without affecting carcass and meat characteristics.

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Medium-heavy pigs; feeding regime; growth performance; carcass quality; meat quality

Introduction

The Italian pig industry relies mostly on heavy pigs slaughtered at 165 kg BW and at least 9 months of age, as prescribed by the Protected Denomination of Origin (PDO) regulations (Bosi & Russo 2004; Lo Fiego et al. 2005), in order to provide thighs suitable for high quality dry-cured ham production. Nevertheless, the PDO pig chain is currently facing a severe threat to its financial viability (Peira et al. 2010). At the same time, Italy is highly dependent on imports of fresh meat (FAOSTAT 2015). Given this situation, different production operations and the development of pig chains where pigs are slaughtered at BW lighter than typical PDO heavy pigs have been proposed as a possible means to cut production costs, limit the oversupply of PDO hams and provide cuts for fresh consumption or processing (Bonadonna et al. 2013; Rossi et al. 2014). The presence of an additional pig chain would make way for a reduction in the supply of thighs for PDO ham production, thereby sustaining the price of the raw material, and reducing the risks associated with market fluctuations. Certified Italian raw materials could be acceptable to the meat industry and to consumers, who are willing to pay the higher supply costs (Peira et al. 2011; Bonadonna et al. 2013). Furthermore, a medium–heavy pig chain not bound by PDO rules could have shorter fattening periods and a better conversion ratio than typical PDO heavy pigs.

It is well known that feeding regime can play a key role in affecting growth traits and meat quality (Lebret 2008). Feeding strategy is the most actively used management tool for controlling quality in meat production, animal performance, and eating and technological quality (Andersen et al. 2005). Therefore, tailored variations in feed availability may lead to a reduction in feed costs and improvement in both intramuscular and subcutaneous fat deposition (Lebret 2008; Averós et al. 2012; Candek-Potokar & Skrlep 2012). Despite reducing average daily growth (ADG) and fattening levels, feed restriction seems to have several advantages, such as improvement in the gain to feed ratio (G:F) (Kim et al. 2014) and reduced maintenance energy requirements (García-Valverde et al. 2008).

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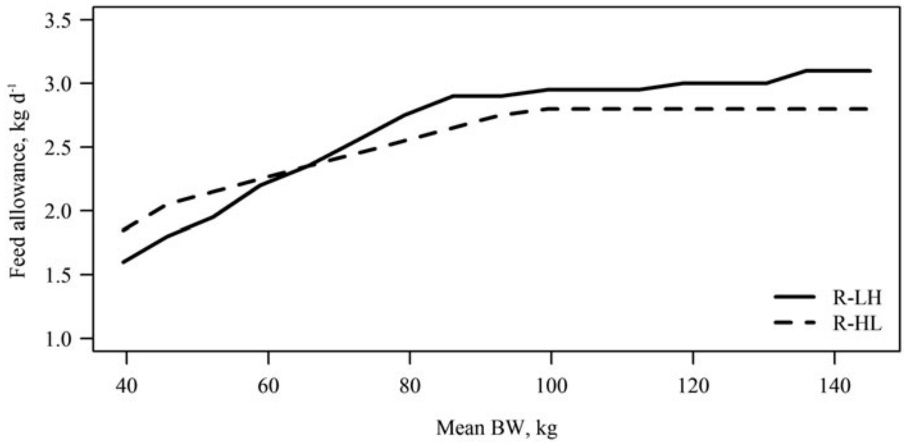

Figure 1. Theoretical feed allowances for pigs on low–high (R-LH) and high–low (R-HL) diet-restricted regimes.

Despite increasing concern, there is still very little data on the growth performance of medium–heavy pigs and on the quality of their products (Peira et al. 2011; Bonadonna et al. 2013; Ratti et al. 2013; Rossi et al. 2014). This study aims to evaluate the effects of different feeding regimes on growth performance, carcass traits and meat quality of 'medium–heavy' pigs slaughtered at around 145 kg BW.

Materials and methods

Animals, housing, feeds and experimental design

All experimental procedures were reviewed and approved by the University of Padova's Ethical Committee for the Care and Use of Experimental Animals (protocol n. 16/2014).

A total of 96 commercial hybrid barrows bred from the Topigs sire line and the Goland dam line were housed in eight pens (12 pigs per pen) at an average 30.4 kg BW. Each pen measured 5.8 × 3.8 m, had a 40% slatted floor and was equipped with a single-space electronic feeder (Compident Pig – MLP, Schauer Agrotronic, Prambachkirchen, Austria) programmed to supply each pig with the planned daily amount of feed and to record the individual amount of feed eaten. After 16 d of acclimation, the pigs in each pen were divided into three groups of four animals. One group was fed *ad libitum* (AL), while the others were fed one of two moderate, quasi AL restricted (R) feeding regimes (with varying feed allowances at increasing BW: restricted low–high, R-LH, or restricted high–low, R-HL) according to theoretical feed allowances (Figure 1) designed on the basis of the nutritional guidelines suggested by the breeding company (Topigs 2012). In detail, R-LH was strictly designed according to the breeding company's guidelines (Topigs 2012), while R-HL aimed to provide a relatively greater amount of nutrients during the early phase, to promote lean growth, and a lower amount of nutrients in the last phase with the intent of improving feed conversion.

Table 1. Ingredient composition (g kg^{-1} as fed) of the diets.

	Days on feed			
Ingredient	0–16	17–51	52–86	87–120
Corn grain	458.8	446.1	516.5	492
Soybean meal	131	131	120	105
Sorghum	120	140	120	120
Wheat bran	71	21	0	0
Wheat middlings	61	101	80	120
Sunflower grain	40	50	55	60
Corn germ	40	50	60	60
Beef tallow	38	29	20	19
Calcium carbonate	12	13	13.5	12.5
Dicalcium phosphate	7.8	4.8	3	0
Sodium chloride	4.8	4.8	4.8	4.8
Vit. and mineral premix[a]	2.5	2.5	2.5	2.5
L-Lys HCl	7	4	3.1	2.7
DL-Met	2.3	1	0.5	0.4
L-Thr	2.7	1.2	0.7	0.7
L-Trp	0.5	0.1	0	0
Choline HCl	0.6	0.5	0.4	0.4

[a]Providing per kg of diet: 9000 U vitamin A, 2000 U vitamin D_3, 1.5 mg B_1, 4 mg vitamin B_2, 3 mg vitamin B_6, 20 µg vitamin B_{12}, 30 mg vitamin E, 2.1 mg vitamin K_3, 22.5 mg pantothenic acid, 25 mg niacin, 0.3 mg folic acid, 0.3 mg biotin, 50 mg Mn, 113 mg Zn, 125 mg Fe, 17.5 mg Cu, 1.75 mg J, 0.375 mg Se.

Throughout the trial, all pigs received four diets according to their average BW (Table 1). In the first period of acclimation (30–44 kg BW), pigs were given AL, a medicated feed containing 180 mg kg^{-1} of doxycycline and colistin. Thereafter, pigs were fed diets providing an average of 13.6 MJ kg^{-1} ME and 164–158 g kg^{-1} CP according to growing phase (Table 2). During the trial, four animals (one AL and three R-LH) died or were removed from the study because of injuries.

Slaughter and carcass data collection

After 119 d on feed, when BW averaged 143 kg, all pigs were moved, after 24 h of fasting to a commercial

Table 2. Chemical composition (g kg^{-1} as fed) and energy content of the diets.

	Days on feed			
	0–16	17–51	52–86	87–120
Analysed nutrient composition[a]				
Dry matter	886	890	894	890
Crude protein (N × 6.25)	166	160	161	157
Starch	471	409	435	430
NDF	125	141	127	139
Ether extract	64	59	50	52
Ash	48	44	43	40
Calculated nutrient composition[b]				
Dry matter	885	884	882	882
ME, MJ kg^{-1}	13.7	13.6	13.6	13.5
Crude protein	164	164	160	158
Lipid	65	56	48	47
Linoleic acid	18	17	17	17
Ash	48	47	45	42
Ca	7.4	7.1	6.8	5.7
P	5.7	5.1	4.7	4.3
Available P	3.5	3.0	2.6	2.2
Calculated total amino acid content[b]				
Lysine	12.4	10.2	9.2	8.7
Methionine	4.9	3.7	3.2	3.1
Threonine	8.3	7.0	6.4	6.3
Tryptophan	2.4	2.0	1.8	1.8
Calculated SID amino acid content[b,c]				
Lysine	11.2	9.0	8.1	7.6
Methionine	4.5	3.4	2.9	2.7
Threonine	7.3	6.0	5.4	5.3
Tryptophan	2.0	1.7	1.5	1.5

[a]Analytical results obtained according to AOAC (2003) by average data from three independent replications.
[b]According to NRC (2012).
[c]SID: standardised ileal digestible.

slaughterhouse located 180 km far from the experimental farm (Magreta di Formigine, MO, Italy). Pigs were stunned by a high concentration of carbon dioxide, than jugulated and exsanguinated. After hair removal and evisceration, carcasss were split along the midline, and warm weight was recorded and used to calculate the dressing percentage. The lean percentage (EU 2014a,b) was calculated by measuring backfat (BF) and *longissimus lumborum* (LL) thicknesses on the left half of each carcass between the 3rd and the 4th to last ribs 8 cm off the midline using an FOM (Fat-O-Meat'er, Carometec, Soeborg, Denmark).

Hot carcasss were processed to obtain the following major cuts: neck (from the 1st cervical to the 3rd thoracic vertebrae, including bones but without skin and subcutaneous tissues); loin (from the 4th thoracic to the last lumbar vertebrae, including ribs); shoulder (the whole forelimb with bones and skin); thigh (the whole hind limb from the femoral head to the distal phalange); backfat; belly (including skin). These cuts were all individually weighed. A section of LL, including the last two lumbar vertebrae, was collected from the left loin of each carcass, placed in individual plastic bags, refrigerated for 24 h, then vacuum-packed at −20 °C pending subsequent analyses. Thighs were deboned after 24 h of chilling, and the weights of the deboned hams were recorded.

Chemical and physical analysis

Ten samples of each diet were collected on-line, pooled, mixed, and sampled to obtain a 1-kg feed sample from which individual sub-samples were collected. Three independent replications of the feed samples were analysed for their proximate composition (AOAC 2003) and NDF content (Van Soest et al. 1991). Starch content was determined after hydrolysis to glucose (AOAC 2003) by liquid chromatography (Bouchard et al. 1988). Dietary ME, SID amino acid and other nutrients were computed from the actual ingredient composition of feeds and the tabular values (NRC 2012) of each ingredient.

Intramuscular fatty acid composition of LL

A portion of each LL sample was ground, mixed and homogenised for 10 s at 4500 *g* (Grindomix GM200; Retsch, Haan, Düsseldorf, Germany), and a sub-sample of 20–30 g was stored at −20 °C until analysis. For fat extraction, a subsample from each LL (4.0 ± 0.01 g) was homogenised with a Hydromatrix (Phenomenex, Castel Maggiore, Bologna, Italy) and sodium sulphate anhydrous, and transferred to 15-mL stainless steel extraction cells for ASE extraction (Thermo Fisher Scientific Inc., Waltham, MA) with petroleum ether as the solvent. Extraction conditions were: temperature, 120 °C; pressure, 10 MPa; static time, 1 min; number of static cycles, 3; rinse, 100%; and purge, 60 s using an 8 mL/sample of fresh solvent (Schäfer 1998). The solvent was evaporated using a rotary film evaporator (Rotavapor® R-205, Buchi Italia s.r.l., Cornaredo, Italy), and samples were kept in an oven at 60 °C for 15 min before being weighed. An aliquot of 40 mg of extracted fat was collected for methylation according to Christie (1993) with minor modifications. Fat samples were transferred to a test tube fitted with a condenser, to which 2 mL of 2% sulphuric acid in methanol was added. The mixture was left overnight in a stoppered tube at 50 °C, then 2 ml of n-heptane and water (4 mL) containing potassium bicarbonate (2%) was added. Samples were centrifuged at 3000 rpm for 10 min, the supernatant was collected using a micropipette and transferred to a vial for GC analysis. The fatty acid methyl esters were analysed using an Agilent 7820 A gas chromatographer (Agilent, Palo Alto, CA) equipped with a flame-ionisation detector and an Omegawax 250 capillary column (Omegawax 250, Supelco, Bellefonte, PA; 30 m, 0.25mm i.d.; film thickness 0.25 µm). A split/splitless injector was used with a split ratio of 1:80 and the carrier gas was hydrogen at a flow rate of 1 mL min^{-1}. An aliquot of the sample was injected under the following GC conditions: initial oven temperature 60 °C held for 1 min, then increased to 173 °C at a rate of 2 °C min^{-1} and held for 30 min, then increased to 185 °C at 1 °C/min and held for 5 min, and finally increased to 220 °C at a rate of 3 °C min^{-1} and held for 19 min. The injector temperature was set at 270 °C and the detector temperature at 300 °C. Individual fatty acid methyl esters were identified by comparison with a standard mixture (18918-1AMP 595 N, Supelco, Bellefonte, PA). The FA composition was expressed as grams per 100 g of total FA.

Meat quality analyses

Muscle pH was measured in triplicate at 45 min post-mortem in the LL sample, and 24 h post-mortem in the LL sample and semimembranosus using a Crison Basic 25 portable pH metre equipped with a Crison 5033 penetration probe (Crison, Barcellona, Spain).

Samples of LL were thawed in vacuum-packaged bags for 24 h at 4 °C, then removed from the packaging, blotted and weighed. Thawing losses were calculated by taking the difference in weight between the fresh and thawed samples as a percentage of initial fresh weight. Lightness (L*) was evaluated in triplicate on LL samples using a reflectance metre (Minolta CR-300, Minolta, Osaka, Japan) equipped with a D65 illuminant and at a 10° angle of observation.

A subsample of LL was ground, mixed and homogenised for 10 s at 4500 *g* (Grindomix GM200; Retsch, Haan, Düsseldorf, Germany) for chemical analyses. Moisture was determined by leaving overnight in an oven at 101–103 °C (method 950.46; AOAC 2003); crude protein (CP) was obtained by multiplying the organic nitrogen by 6.25 (Kjeldhal method; AOAC 2003); fat was determined by extraction with petrol ether (method 991.36; AOAC 2003); and ash was determined by mineralisation in a muffle furnace at 550 °C (method 920.153; AOAC 2003).

Cooking loss was determined on a 2.5 cm thick subsample of LL, which was weighed and sealed in a plastic bag, cooked in a water bath at 75 °C for 50 min to a core temperature of 70 °C. Cooked samples were cooled to room temperature, blotted dry, and weighed again. Cooking loss percentage was computed by dividing the difference between the pre- and post-cooked weights by the pre-cooked weight. Five cylindrical cores of 1 cm^2 were collected from the same subsample and sheared perpendicularly with a Lloyd® (Bognor Regis, UK) LS 5 series Warner-Bratzler shearing device (shearing velocity 1 mm s^{-1}) using the NEXIGEN Plus 3 software (Bognor Regis, UK).

Statistical analysis

All data were analysed using the SAS MIXED procedure (SAS, 2015) according to the following linear model:

$$y_{ijk} = \mu + \text{feeding regime}_i + \text{pen}_j + e_{ijk}$$

where y_{ijk} is the observed trait, μ is the overall intercept of the model, feeding regime$_i$ is the fixed effect of the *i*th feeding regime (*i*: 1 = AL, 2 = R-HL, 3 = R-LH), pen$_j$ is the random effect of the *j*th pen ($j = 1,\ldots, 8$) and e_{ijk} is the random residual. Pen and the residuals were assumed to be independently and normally distributed with mean zero and variances of σ_j^2 and σ_e^2, respectively.

Orthogonal contrasts were estimated between the least square means of the feeding regimes (AL vs R and R-HL vs R-LH).

Results and discussion

The development of a medium–heavy pig chain is of growing interest as a possible strategy for diversifying the production objectives of the Italian pig sector. However, achievement of these goals requires careful optimisation of pig production procedures. Manipulation of feed intake (FI) could be an effective tool for adjusting nutrient utilisation, animal performance and the degree of carcass fattening. The adequacy of the feed allowance, which is dependent on genetic background and desired fattening level, can be assessed empirically by comparing actual animal performances at different levels of feed restriction (Whittemore & Kyriazakis, 2006).

Growth traits

Body weight at slaughter in this trial ranged 140.1 kg (R-HL) to 145.1 kg (AL) after 120 days on feed (Table 3). Overall growth rate was on average close to 940 g d^{-1}, and average G:F was close to 0.38. The growth rate and G:F of the medium–heavy pigs in this study were 14.1–32.0% and 13.0–35.5%, respectively, better than those reported in several studies for heavy pigs reared according to PDO guidelines (Della Casa et al. 2010; Prandini et al. 2013; Gallo et al. 2014). In general, the growth traits observed in the present study were comparable to those reported for barrows slaughtered at 110–125 kg BW (Morales et al. 2011; Tous et al. 2013).

Table 3. Growth performance of pigs fed *ad libitum* (AL) or on a restricted (R) low–high (R-LH) or high–low (R-HL) feeding regime.

	Feeding regime[a]					Contrasts (*p* value)		
	AL	R-LH	R-HL	SEM	*p*	AL vs R	R-LH vs R-HL	RMSE
BW, kg								
0 d	30.3	30.5	30.5	0.75	0.97	0.82	0.95	4.151
16 d	44.5	43.9	44.1	0.93	0.92	0.68	0.92	5.157
51 d	82.5	81.1	80.3	1.10	0.34	0.18	0.60	6.097
86 d	115.8	112.9	111.8	1.17	0.044	0.017	0.48	6.476
120 d	145.1	142.7	140.1	1.38	0.035	0.028	0.19	7.620
Daily gain, g d^{-1}								
0–16 d	925	879	881	34.7	0.34	0.14	0.95	138.4
17–51 d	1098	1074	1045	18.4	0.026	0.024	0.15	76.5
52–86 d	952	910	900	20.1	0.16	0.06	0.73	111.4
87–120 d	863	873	833	24.6	0.37	0.70	0.18	113.6
0–120 d	966	942	921	10.8	0.004	0.003	0.10	51.2
Daily feed intake, g								
0–16 d	1387	1303	1338	32.3	0.09	0.042	0.36	146.4
17–51 d	2532	2345	2325	40.2	<0.001	<0.001	0.67	186.4
52–86 d	2843	2713	2650	47.7	0.011	0.005	0.34	253.2
87–120 d	3031	2809	2683	55.6	<0.001	<0.001	0.11	307.5
0–120 d	2633	2465	2410	30.1	<0.001	<0.001	0.20	166.5
Total feed intake, kg	313	293	287	3.58	<0.001	<0.001	0.20	19.82
Gain:feed								
0–16 d	0.641	0.647	0.632	0.023	0.62	0.92	0.33	0.058
17–51 d	0.431	0.453	0.445	0.005	0.008	0.003	0.27	0.027
52–86 d	0.336	0.335	0.339	0.005	0.82	0.79	0.58	0.027
87–120 d	0.285	0.311	0.311	0.006	0.001	<0.001	0.97	0.031
0–120 d	0.368	0.383	0.383	0.003	<0.001	<0.001	0.88	0.018

[a]The number of observations was 31 for AL, 29 for R-LH and 32 for R-HL.

The feeding regime significantly affected most of the pigs' growth traits. AL-fed pigs had a greater BW from 86 days on feed onwards, and were 2.6% heavier than R-fed pigs at the end of the trial ($p < 0.05$). This was due to the greater growth rate exhibited by AL-fed pigs, which was 3.7% faster than R fed pigs ($p < 0.01$). The greater ADG in pigs under the AL regime than in R-fed pigs is consistent with previous literature (Affentranger et al. 1996; Whittemore & Kyriazakis, 2006; Boddicker et al. 2011; Kim et al. 2014). As expected, the FI of AL-fed pigs was greater ($p < 0.01$) than that of R-fed pigs in all growing phases, with the exception of the first 16 days on feed when all pigs were on the same feeding regime. Pigs fed AL consumed nearly 20 kg more feed than R-fed pigs during the trial, although this greater FI was not compensated for with a greater growth rate, as their G:F was nearly 4% lower than that of the R-fed pigs. Indeed, we can assume from actual FI and ADG that R-fed pigs would have required nearly 10 kg less feed than AL-fed pigs to reach a final BW of 145 kg. Kim et al. (2014) also observed an 8% increase in G:F when the feed allowance was reduced by 15% compared with an AL-feeding regime. However, Boddicker et al. (2011) did not find any differences in feed efficiency between the AL-feeding regime and a feed allowance equal to 75% of AL, although greater feed restriction (55% of AL) resulted in a decrease in the G:F of growing pigs. Therefore, given a specific genetic background, it may be argued that feed allowances may be manipulated within narrow limits, beyond which further restriction is not worthwhile. No differences were detected between the two R-feeding regimes, which resulted in the same G:F and comparable growth performances.

Carcass characteristics and meat quality traits

As reported in Table 4, feeding regime significantly affected carcass weight, with AL-fed pigs yielding carcasss nearly 3% heavier than R-fed pigs ($p = 0.013$). This was entirely due to the greater weight of AL-fed pigs at slaughter, as feeding regime did not affect the dressing percentage. Nor did feeding regime affect the depth of BF and loin assessed through FOM, and the lean meat percentage. Average carcass yield observed in this study was lower than the dressing percentage generally reported for typical Italian heavy pigs (Della Casa et al. 2010; Prandini et al. 2013; Schiavon et al. 2015), but was comparable to the dressing percentage observed in barrows slaughtered at between 120 and 130 kg BW (Peinado et al. 2008; Morales et al. 2011; Rodríguez-Sánchez et al. 2011). The pigs in this study also yielded carcasss characterised by a lower BF depth than typical Italian heavy pigs (Fabro et al. 2013; Minelli et al. 2013; Prandini et al. 2013).

The feeding regime exerted minor effects on the weight of primal cuts (Table 4). Pigs fed with AL tended to yield thighs 2.3% heavier than those from

Table 4. Weight of carcasss and major cuts of pigs fed *ad libitum* (AL) or on a restricted low–high (R-LH) or high–low (R-HL) feeding regime.

	Feeding regime[a]					Contrasts (*p* value)		
	AL	R-LH	R-HL	SEM	*p*	AL vs R	R-LH vs R-HL	RMSE
Carcass, kg	116.2	114.0	111.4	1.14	0.012	0.013	0.10	6.308
Hot carcass yield, %	80.0	79.9	79.5	0.274	0.22	0.24	0.22	1.369
Backfat depth, mm[b]	24.8	24.2	22.5	0.904	0.16	0.18	0.18	5.004
Loin depth, mm[b]	57.1	56.7	54.0	1.29	0.19	0.26	0.16	7.145
Lean meat, %[c]	54.1	54.4	54.7	0.481	0.66	0.45	0.63	2.663
Weight, kg of:								
Neck	4.01	4.01	3.93	0.055	0.53	0.57	0.34	0.3061
Shoulder	7.88	7.79	7.77	0.090	0.63	0.35	0.87	0.4976
Loin	8.24	8.12	8.01	0.102	0.26	0.15	0.44	0.5645
Thigh	14.89	14.69	14.42	0.141	0.06	0.05	0.17	0.7808
Boneless thigh	9.67	9.61	9.45	0.081	0.13	0.14	0.17	0.4488
Belly	6.57	6.42	6.21	0.083	0.009	0.013	0.07	0.4609
Backfat	4.46	4.34	3.97	0.141	0.036	0.07	0.07	0.7822

[a]The number of observations was 31 for AL, 29 for R-LH and 32 for R-HL.
[b]Measured between the third and the fourth last ribs 8 cm off the midline.
[c]Estimated according to the Commission Implementing Decision 2014/38/EU and further amendments (EU 2014a,b).

Table 5. Physical and chemical characteristics of meat of pigs fed *ad libitum* (AL) or on a restricted (R) low–high (R-LH) or high–low (R-HL) feeding regime.

	Feeding regime[a]					Contrasts (*p* value)		
	AL	R-LH	R-HL	SEM	*p*	AL vs R	R-LH vs R-HL	RMSE
pH of *Longissimus lumborum*, LL:								
at 45 min	5.80	5.79	5.71	0.06	0.46	0.52	1.02	0.314
at 24 h	5.39	5.40	5.38	0.01	0.68	0.96	0.39	0.069
pH of *Semimembranosus*, 24 h	5.36	5.31	5.34	0.03	0.37	0.25	0.39	0.131
Chemical composition of LL:								
Moisture, %	72.4	72.6	72.1	0.27	0.45	0.049	0.21	1.277
Crude protein, % DM	22.4	22.7	22.7	0.21	0.40	0.18	1.00	0.847
Fat, % DM	3.92	3.45	3.86	0.20	0.22	0.28	0.17	1.130
Ash, % DM	1.13	1.14	1.14	0.01	0.26	0.10	0.91	0.044
Color lightness (L^*) of LL at 24 h	46.5	45.6	47.2	2.13	0.010	0.92	0.002	1.986
Water holding capacity of LL, %:								
Thawing loss	12.1	12.1	12.8	0.50	0.20	0.42	0.12	1.782
Cooking loss	30.7	30.6	30.6	0.35	0.98	0.85	0.98	1.411
Shear force of LL, kg	2.57	2.66	2.52	0.06	0.24	0.79	0.09	0.329

[a]The number of observation was 31 for AL, 29 for R-LH and 32 for R-HL.

R-fed pigs ($p = 0.05$). However, differences between feeding regimes disappeared when the thighs were deboned. This suggests that the differences in thigh weight among pigs on different feeding regimes could be mainly due to different levels of subcutaneous fat depots on the thighs. Feeding pigs AL also increased the weight of the belly (+ 4.1%) and nominally, that of backfat (+ 7.2%) compared with R-fed pigs ($p = 0.013$ and 0.07, respectively). Therefore, the increase in the weight of fat cuts was proportionally greater than the increase in carcass weight in pigs fed with AL compared with R-fed pigs, suggesting that the higher feed allowance in the AL-feeding regime resulted in slightly fatter carcasss. Findings from this study are in agreement with García-Valverde et al. (2008), who reported minor effects of feeding levels on the carcass characteristics of Iberian barrows slaughtered at 150 kg BW.

Feeding regime did not affect the physical and chemical characteristics of the meat (Table 5), with the sole exception of LL lightness, which was greater in R-HL than in R-LH fed pigs ($p < 0.05$). Results of this study are in agreement with findings of García-Valverde et al. (2008), who reported that a feed restriction from 0.95 AL to 0.70 AL did not affect the chemical composition of the lean parts of shoulders and hams. Average intramuscular fat (IMF) content of LL was close to 3.7%, with only nominal differences among different feeding regimes. The IMF content found in the present study was intermediate between the lower content reported for pigs slaughtered around 110 kg BW (Wood et al. 2013; Tous et al. 2014) and the generally greater content for typical Italian heavy pigs (Mordenti et al. 2012; Minelli et al. 2013), and was comparable to the IMF values found by Rossi et al. (2014) in medium–heavy pigs slaughtered at around 135 kg BW. Thawing losses observed in this study were consistent with the values reported for pigs slaughtered at 120–130 kg BW (Peinado et al. 2008;

Table 6. Fatty acid composition of *longissimus lumborum* intramuscular fat of pigs fed *ad libitum* (AL) or on a restricted (R) low–high (R-LH) or high–low (R-HL) feeding regime.

	Feeding regimes[a]					Contrasts (*p* value)		
	AL	R-LH	R-HL	SEM	*p*	AL vs R	R-LH vs R-HL	RMSE
Saturated fatty acids (SFA) %								
C14:0	1.75	1.68	1.68	0.033	0.22	0.08	0.99	0.164
C16:0	23.98	22.64	23.23	0.303	0.007	0.004	0.15	1.589
C18:0	10.35	9.69	9.92	0.320	0.25	0.11	0.58	1.554
C20:0	0.14	0.12	0.14	0.011	0.54	0.78	0.28	0.057
Total SFA	37.58	35.50	36.35	0.521	0.013	0.006	0.224	2.679
Monounsaturated fatty acids (MUFA) %								
C16:1 *n*-9	0.40	0.41	0.40	0.022	0.92	0.78	0.77	0.122
C16:1 *n*-7	4.04	4.07	3.81	0.126	0.30	0.53	0.16	0.698
C18:1 *n*-9	38.41	40.93	39.93	1.038	0.20	0.09	0.47	5.399
C18:1 *n*-7 *cis*	7.04	6.14	6.49	0.999	0.78	0.52	0.79	5.045
C20:1 *n*-9	0.68	0.65	0.70	0.032	0.55	0.91	0.28	0.179
Total MUFA	51.40	53.10	52.22	0.440	0.026	0.019	0.15	2.381
Polyunsaturated fatty acids (PUFA) %								
C18:2 *n*-6	8.70	9.06	9.15	0.332	0.59	0.31	0.85	1.836
C18:2 *n*-6 *trans*	0.24	0.21	0.24	0.040	0.60	0.57	0.39	0.140
C18:3 *n*-3	0.39	0.41	0.40	0.018	0.72	0.43	0.81	0.102
C20:2 *n*-6	0.36	0.35	0.37	0.019	0.81	0.85	0.54	0.092
C20:3 *n*-6	0.13	0.13	0.10	0.019	0.44	0.45	0.31	0.103
C20:4 *n*-6	0.61	0.59	0.58	0.038	0.80	0.53	0.86	0.193
Total PUFA	11.01	11.39	11.43	0.371	0.67	0.38	0.84	2.055
Minor fatty acids[b]	1.99	2.13	2.07	0.103	0.40	0.23	0.53	0.391
n-3	0.58	0.59	0.57	0.028	0.86	0.90	0.60	0.152
n-6	9.56	9.89	10.00	0.348	0.64	0.36	0.77	1.924
n-6/*n*-3	17.10	17.31	17.90	0.587	0.60	0.48	0.48	3.247

[a]The number of observation was 31 for AL, 29 for R-LH and 32 for R-HL.
[b]Minor Fatty acids include: C6:0, C8:0, C10:0, C11:0, C12:0, C13:0, C15:0 iso, C15:0 anteiso, C15:0, C17:0, C18:0 iso, C19:0, C21:0, C22:0, C23:0, C24:0, C10:1, C14:1, C15:1, C16:1 iso, C17:1 *n*-7, C18:1 isomers, C21:1 *n*-9, C24:1 *n*-9, C18:2 isomers, C18:2 *n*-6 *trans*, C18:3 *n*-6, CLA, C20:3 *n*-3, C20:5 *n*-3, C22:1 *n*-9, C22:2 *n*-6, C22:6 *n*-3.

Rodríguez-Sánchez et al. 2011), whereas cooking losses were greater. The pH at 24 h was also lower than the values usually reported for pork meat, irrespective of BW at slaughter (Minelli et al. 2013; Tous et al. 2014), which could partly explain the greater cooking losses given that a strong negative correlation between pH at 24 h and cooking losses has been found (Miar et al. 2014). The shear force of LL observed in this study was in good agreement with the values reported by Rodríguez-Sánchez et al. (2011) for commercial crossbred gilts and barrows slaughtered at 130 kg BW, but was lower than the shear force values found in pigs slaughtered at between 110 and 120 kg BW (Peinado et al. 2008; Miar et al. 2014). Bee et al. (2006) reported that a 0.8 AL restriction of growing pigs increased the shear forces and cooking losses of the LL, semimembranosus and semitendinosus muscles.

The fatty acid proportion of IMF of the LL muscle (Table 6) was characterised by greater proportions of total saturated fatty acids in pigs fed with AL ($p < 0.01$), particularly palmitic acid ($p < 0.01$), and lower proportions of monounsaturated fatty acids (MUFAs) ($p < 0.05$), and among these oleic acid ($p = 0.09$), than R-fed pigs. However, the feeding regime did not affect the *n*-3, *n*-6 FA and the *n*-3/*n*-6 ratio in LL intramuscular fat. In general, the fatty acid composition of intramuscular LL fat found in this study was consistent with the values reported by Tous et al. (2014) for pigs slaughtered at around 125 kg BW, and with those reported by Della Casa et al. (2010) for the typical Italian heavy pig. Kim et al. (2014) reported that a 0.85 AL restriction to the diet of growing pigs altered the adipose tissue expression of key enzymes down-regulating acetyl-CoA carboxylase and fatty acid synthase and up-regulating hormone sensitive lipase and lipoprotein lipase during the finishing period, suggesting decreased capacity of *de novo* synthesis of fatty acids and enhanced lipolytic activity in the adipose tissue of restricted pigs. This could explain the greater proportion of palmitic acid observed in AL adipose tissue. Although meat processors value greater saturation as it contributes to improving the taste and technological properties of products (Wood et al. 2003), there is growing concern about the role of these acids in the pathogenesis of coronary disease in humans, and a high intake of them is therefore discouraged (Chowdhury et al. 2014).

Conclusions

The development of medium–heavy pig chain could support the diversification of a way to diversify the

Italian pig production system and reduce the oversupply of PDO pigs, which is affecting the profitability of pig producers and the whole heavy pig chain. This study found evidence that pigs reared under this system can display considerable growth performance and valuable carcass and meat quality traits. Furthermore, this trial highlighted that, despite slightly decreasing growth rate, moderate restriction in the feeding regime seems advisable as it improved feed efficiency and could cut feed costs compared with an AL-feeding regime, without affecting carcass and meat characteristics. Given the moderate degree of feed restriction, the two restricted regimes used in this study did not elicit different growth performances or affected meat quality

Nevertheless, considering the overall performances, R-LH regime seems to induce the highest benefit-cost ratio for this specific commercial crossbreed.

Disclosure statement

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.

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