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

Mirco Dalla Bona, Stefano Schiavon, Luca Carraro and Luigi Gallo
Dipartimento di Agronomia Animali Alimenti Risorse Naturali e Ambiente, University of Padova, Legnaro, Italy

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.

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 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).
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, Schaer 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.

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

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

| 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\(_3\), 20 μg vitamin B\(_6\), 30 mg vitamin E, 2.1 mg vitamin K\(_1\), 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 I, 0.375 mg Se.
slaughterhouse located 180 km far from the experimental farm (Magreta di Formigine, MO, Italy). Pigs were stunned by a high concentration of carbon dioxide, then jugulated and exsanguinated. After hair removal and evisceration, carcasses were split along the midline, than jugulated and exsanguinated. After hair were stunned by a high concentration of carbon dioxide and were 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, 0.25 mm 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 (Crisson, 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).

Carcass fatness 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$^\text{®}$ (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:

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

where $y_{ijk}$ is the observed trait, $\mu$ is the overall intercept of the model, feeding regime is the fixed effect of the $i$th feeding regime ($i$: 1 = AL, 2 = R-HL, 3 = R-LH), $\text{pen}_j$ 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 $\sigma^2_j$ and $\sigma^2_e$, 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).
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 carcasses 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 carcasses 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...
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 \((p = 0.013 \text{ and } 0.07, \text{ respectively})\). 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 carcasses. Findings from this study are in agreement with Garcia-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.

| Saturated fatty acids (SFA) % | AL      | R-LH    | R-HL    | SEM     | p       | AL vs R | R-LH vs R-HL | RMSE  |
|------------------------------|---------|---------|---------|---------|---------|---------|--------------|-------|
| C14:0                        | 1.75    | 1.68    | 1.62    | 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) % | AL       | R-LH     | R-HL     | SEM     | p       | AL vs R | R-LH vs R-HL | RMSE  |
|-------------------------------------|----------|----------|----------|---------|---------|---------|--------------|-------|
| C16:1 n-9                          | 0.40     | 0.41     | 0.40     | 0.022   | 0.92    | 0.78    | 0.77         | 0.122 |
| C16:1 n-12                         | 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    | 0.99    | 0.47         | 5.399 |
| C18:1 n-12 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) % | AL        | R-LH     | R-HL     | SEM     | p       | AL vs R | R-LH vs R-HL | RMSE  |
|-------------------------------------|-----------|----------|----------|---------|---------|---------|--------------|-------|
| C18:2 n-6                           | 8.70      | 9.06     | 9.15     | 0.332   | 0.59    | 0.31    | 0.85         | 1.386 |
| 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 acidsb                 | AL        | R-LH     | R-HL     | SEM     | p       | AL vs R | R-LH vs R-HL | RMSE  |
|------------------------------------|-----------|----------|----------|---------|---------|---------|--------------|-------|
| 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    | 0.387   | 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, C24:0, C10:1, C14:1, C15:1, C16:1 iso, C17:1 n-7, C17:1 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 cross-bred 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, semimembranous 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 (MUFA) (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 crossbred.

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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References

Affentranger P, Gerwig C, Seewer GJF, Schwörer D, Künzi N. 1996. Growth and carcass characteristics as well as meat and fat quality of three types of pigs under different feeding regimens. Livest Prod Sci. 45:187–196.

Andersen HJ, Oksbjerg N, Young JF, Therkildsen M. 2005. Feeding and meat quality: a future approach. Meat Sci. 70:543–554.

AOAC. 2003. Official methods of analysis, 17th ed. Gaithersburg, MD: AOAC International.

Averós X, Brossard L, Dourmad JY, de Greef KH, Edwards SA, Meunier-Salaün MC. 2012. Meta-analysis on the effects of the physical environment, animal traits, feeder and feed characteristics on the feeding behaviour and performance of growing-finishing pigs. Animal. 6:1275–1289.

Bee G, Calderini M, Bioley C, Guex G, Herzog W, Lindemann MD. 2006. Changes in the histochemical properties and meat quality traits of porcine muscles during the growing-finishing period as affected by feed restriction, slaughter age, or slaughter weight. J Anim Sci. 85:1275–1289.

Boddicker N, Gabler NK, Spurlock ME, Nettleton D, Dekkers JCM. 2011. Effects of ad libitum and restricted feed intake on growth performance and body composition of Yorkshire pigs selected for reduced residual feed intake. J Anim Sci. 89:40–51.

Bonadonna A, Aceto P, Peira G, Varese E. 2013. Hypothesis for relaunch of the pig farming sector in Piedmont: medium/heavy pig meat as the raw material in the production of cooked ham. Quality - Acces La Succes. 14:114–118.

Bosi P, Russo V. 2004. The production of the heavy pig for high quality processed products. Ital J Anim Sci. 3:309–321.

Bouchard J, Choret E, Overend RP. 1988. High-performance liquid chromatographic monitoring of carbohydrate fractions in partially hydrolyzed corn starch. J Agric Food Chem. 36:1188–1192.

Candek-Potokar M, Skrle M. 2012. Factors in pig production that impact the quality of dry-cured ham: a review. Animal. 6:327–338.

Chowdhury R, Warnakula S, Kunutsor S, Crowe F, Ward HA, Johnson L, Franco OH, Butterworth AS, Forouhi NG, Thompson SG, et al. 2014. Association of dietary, circulating, and supplement fatty acids with coronary risk: a systematic review and meta-analysis. Ann Intern Med. 160:398–406.

Christie WW, editor. 1993. Advances in lipid methodology - Two. Dundee, UK: Oily Press.

Della Casa G, Bochicchio D, Faeti V, Marchetto G, Poletti E, Rossi A, Panciroli A, Mordenti A, Brogna N. 2010. Performance and fat quality of heavy pigs fed maize differing in linoleic acid content. Meat Sci. 84:152–158.

EU. 2014a. Commission implementing decision of 24 January 2014 authorising methods for grading pig carcasses in Italy (notified under document C(2014) 279), Pub. L. No. 2014/38/EU (2014), Official J L. 23:35–40.

EU. 2014b. Corrigendum to Commission Implementing Decision 2014/38/EU of 24 January 2014 authorising methods for grading pig carcasses in Italy (OJL 23, 28.1.2014) (2014). Official J L. 54:22.

Fabro C, Sgorlon S, Guaitt1, Stefanon B, Susmel PA. 2013. Productive response of Duroc x large white and commercial hybrid x Large white crosses fed high and low protein diets. Ital J Anim Sci. 12:507–512.

FAOSTAT. 2015. Food and agriculture organization of the united nations: statistics division [Internet]. Available from: http://faostat3.fao.org

Gallo L, Dalla Montà G, Carraro L, Cecchinato A, Carnier P, Schiavon S. 2014. Growth performance of heavy pigs fed restrictively diets with decreasing crude protein and indispensible amino acids content. Livest Sci. 161:130–138.

García-Valverde R, Barea R, Lara L, Nieto R, Aguillera JO. 2008. The effects of feeding level upon protein and fat deposition in Iberian heavy pigs. Livest Sci. 114:263–273.

Kim JS, Ingale SL, Lee SH, Choi YH, Kim EH, Lee DC, Kim YH, Chae BJ. 2014. Impact of dietary fat sources and feeding level on adipose tissue fatty acids composition and lipid metabolism related gene expression in finisher pigs. Anim Feed Sci Technol. 196:60–67.

Lebret B. 2008. Effects of feeding and rearing systems on growth, carcass composition and meat quality in pigs. Animal. 2:1548–1558.

Lo Fiego DP, Santoro P, Macchiioni P, De Leonibus E. 2006. Influence of genetic type, live weight at slaughter and carcass fatness on fatty acid composition of subcutaneous adipose tissue of raw ham in the heavy pig. Meat Sci. 69:107–114.

Miar Y, Plastow GS, Moore SS, Manafiazar G, Charagu P, Kemp RA, Van Haandel B, Huisman AE, Zhang CY, McKay...
RM, et al. 2014. Genetic and phenotypic parameters for carcass and meat quality traits in commercial crossbred pigs. J Anim Sci. 92:2869–2884.

Minelli G, Macchioni P, Ielo MC, Santoro P, Lo Fiego DP. 2013. Effects of dietary level of pantothenic acid and sex on carcass, meat quality traits and fatty acid composition of thigh subcutaneous adipose tissue in Italian heavy pigs. Ital. J Anim Sci. 12:329–336.

Morales JL, Cámara L, Berrocoso JD, López JP, Mateos GG, Serrano MP. 2011. Influence of sex and castration on growth performance and carcass quality of crossbred pigs from 2 Large White sire lines. J Anim Sci. 89:3481–3489.

Mordenti AL, Martelli G, Brogna N, Nannoni E, Vignola G, Zaghini G, Sardi L. 2012. Effects of a soybean-free diet supplied to Italian heavy pigs on fattening performance, and meat and dry-cured ham quality. Ital J Anim Sci. 11: 459–465.

NRC. 2012. Nutrient Requirement of Swine. 10th ed. Washington: National Academy Press.

Peinado J, Medel P, Fuentetaja A, Mateos GG. 2008. Influence of sex and castration of females on growth performance and carcass and meat quality of heavy pigs destined for the dry-cured industry. J Anim Sci. 86:1410–1417.

Peira G, Aceto P, Bonadonna A. 2011. Hypotheses for relaunch of the pig farming sector of Piedmont: medium heavy swine as raw material for feeding the speck supply chain. Sci J Warsaw Univ Life Sci. 11: 88–97.

Peira G, Varese E, Bonadonna A, Arese MT. 2010. Development prospects for the Piedmont swine supply chain: medium heavy swine. Calitatea - Acces La Succes. 116:733–737.

Prandini A, Sigolo S, Morlacchini M, Grilli E, Fiorentini L. 2013. Microencapsulated lysine and low-protein diets: effects on performance, carcass characteristics and nitrogen excretion in heavy growing-finishing pigs. J Anim Sci. 91:4226–4234.

Ratti S, Rossi R, Pastorelli G, Corino C. 2013. Nutritional and sensory quality of cooked ham from 135 kg lw pigs. Proc Nutr Soc. 72:E319.

Rodríguez-Sánchez JA, Sanz MA, Blanco M, Serrano MP, Joy M, Latorre MA. 2011. The influence of dietary lysine restriction during the finishing period on growth performance and carcass, meat, and fat characteristics of barrows and gilts intended for dry-cured ham production. J Anim Sci. 89:3651–3662.

Rossi R, Ratti S, Pastorelli G, Crotti A, Corino C. 2014. The effect of dietary vitamin E and verbascoside on meat quality and oxidative stability of longissimus dorsi muscle in medium-heavy pigs. Food Res Int. 65:88–94.

SAS. 2015. SAS/STAT® 14.1 User’s Guide. Cary (NC): SAS Institute Inc.

Schäfer K. 1998. Accelerated solvent extraction of lipids for determining the fatty acid composition of biological material. Anal Chim Acta. 358:69–77.

Schiavon S, Carraro L, Dalla Bona M, Cesaro G, Carneri P, Tagliapietra F, Sturaro E, Galassi G, Malagutti L, Trevisi E, et al. 2015. Growth performance, and carcass and raw ham quality of crossbred heavy pigs from four genetic groups fed low protein diets for dry-cured ham production. Anim Feed Sci Technol. 208:170–181.

Topigs. 2012. Feeding manual Talent. Available from: http://www.varkens.nl/dier/voeren-vleesvarkens.

Tous N, Lizardo R, Vilà B, Gispert M, Font-i-Furnols M, Esteve-Garcia E. 2014. Effect of reducing dietary protein and lysine on growth performance, carcass characteristics, intramuscular fat, and fatty acid profile of finishing barrows 1. J Anim Sci. 92:129–140.

Tous N, Lizardo R, Vilà B, Gispert M, Font-i-Furnols M, Esteve-Garcia E. 2013. Effect of a high dose of CLA in finishing pig diets on fat deposition and fatty acid composition in intramuscular fat and other fat depots. Meat Sci. 93:517–524.

Van Soest PJ, Robertson JB, Lewis BA. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J Dairy Sci. 74:3583–3597.

Whittemore CT, Kyriazakis I, editors. 2006. Whittemore’s science and practice of pig production. 3rd ed. Oxford, UK: Blackwell Publishing Ltd.

Wood J, Richardson R, Nute G, Fisher A, Campo M, Kasapidou E, Sheard P, Enser M. 2003. Effects of fatty acids on meat quality: a review. Meat Sci. 66:21–32.

Wood JD, Lambe NR, Walling GA, Whitney H, Jagger S, Fullarton PJ, Bayntun J, Hallett K, Bünger L. 2013. Effects of low protein diets on pigs with a lean genotype. 1. Carcass composition measured by dissection and muscle fatty acid composition. Meat Sci. 95:123–128.