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Effect of growth rate on live performance, carcass and green thigh traits of finishing Italian heavy pigs

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ABSTRACT
This study aimed at investigating the effects of growth rate (GR) on live performance, carcass and dressed green ham (DRHAM) traits of finishing heavy pigs managed in accordance with the regulations governing the production of Protected Denomination of Origin (PDO) dry-cured hams. Data were obtained from 233 crossbred pigs restrictively fed from 90 to 165 kg BW. Individual BW, daily feed intake, and weights of carcass and main cuts were recorded. Thighs were measured for subcutaneous fat thickness, analysed for fatty acid composition of subcutaneous fat, and dry-cured hams were weighed. Records were classified according to GR quartile, calculated using the residuals of a statistical model that included the effects of pen, sex and diet. Data were analysed using the same model with the addition of the effect of GR quartile. Average GR ranged from 578 in the first quartile to 748 g/d in the fourth. Final BW and weights of carcass, DRHAM and dry-cured ham increased as the GR quartile increased (p < .01). An increase in GR improved feed efficiency linearly (p < .001) and tended to increase the thickness of subcutaneous fat of DRHAM, whereas seasoning losses decreased linearly with increasing average GR. In conclusion, targeting the GR of finishing pigs at a minimum of 750 g/d and consequently increasing final BW to around 175–180 kg may be a way to improve feed efficiency and some quality traits of DRHAM.

Introduction
Italian pig production is traditionally aimed at providing green hams for the production of Protected Denomination of Origin (PDO) dry-cured hams, and must, therefore, conform to the regulations governing PDO products (EU 2012) as well as the technical specifications of green hams established by the dry-cured ham consortia. As the way in which pigs are managed and fed has an impact on green ham properties (Candek-Potokar & Skrlep 2012), the regulations governing PDO dry-cured ham production also cover the husbandry and feeding procedures of pigs, in accordance with a combination of empirical and scientific criteria (Bosi & Russo 2004). Weight and age at slaughter are among the most important husbandry features of Italian pigs raised for dry-cured ham production, as a minimum for BW of lot of 160 kg ±10% and a minimum age at slaughter of 9 months have been established by the consortia to attain an acceptable degree of maturity of the meat. These thresholds have been set on the basis of experimental data showing that the age and BW of pigs at slaughter are related to ham weight, subcutaneous fat thickness and composition of green hams, seasoning losses, and overall aptitude for seasoning (Virgili et al. 2003; Lo Fiego et al. 2005; Candek-Potokar & Skrlep 2012). Conversely, the effect of growth rate (GR) on the overall performance of heavy pigs has been given little attention and is generally considered to be a mere consequence of the required age and weight at slaughter. According to production regulations, husbandry and feeding procedures should be aimed at attaining a ‘moderate growth rate’ (EEC 1992). The benchmark value for the finishing GR of Italian heavy pigs is placed at around 650 g/d (BPEX 2016), although studies dealing with Italian heavy pig production show considerable variation in GR (ranging for instance from 590 g/d in Corino et al. 2008, to 820 g/d in Prandini et al. 2013, with initial BW between 80 and 100 kg). Growth rate impacts on feed efficiency, carcass weight and composition and herd profitability (Nguyen & McPhee 2005; Yang et al. 2012), and is recognised as one of...
the most important traits in pig production (Niemi et al. 2015). Feeding strategy and diet composition can affect GR (Lebret 2008), and as the growth potential of pigs has increased as a consequence of selection procedures (Lo Fiego et al. 2005), it is now time to reconsider the target GR for Italian heavy pigs. This study investigated the relationships between GR and performance, carcass and green ham characteristics of finishing heavy pigs managed in accordance with PDO regulations.

Materials and methods

Origin of the data

The data for this study came from a feeding trial which involved three batches of 80 crossbred pigs each (120 gilts and 120 barrows), offspring of Large White-derived crossbred sows mated to C21 sire-line boars (Goland, Gorzagri, Fonzaso, BL, Italy). The characteristics of the pigs, the feeding regimes and the diets used are described in detail by Gallo et al. (2014), while information about carcass quality and properties of the green hams are provided by Gallo et al. (2015, 2016).

Briefly, in each batch, 20 pigs were allotted to one of four dietary treatments differing in crude protein (CP) and indispensable amino acid (AA) contents. Feed ingredients consisted of corn, barley, wheat grain, soybean meal with wheat grain yielded feeds with an average CP ranging from 140 to 110 g/kg, while crystalline AA were added to obtain a dietary lysine content ranging on average between 6.5 and 5.3 g/kg. Pigs were housed in groups of 10 (2 pens per dietary treatment per batch), gilts and barrows together. Each pen was equipped with a single-space electronic feeder (Compident Pig – MLP; Schauer Agrotronic, Prambachkirchen, Austria), and pigs were fed on a restricted feeding scale that was adjusted at 2-week intervals to provide 2.4–3.2 kg/d of pelleted feed from the first to the last week on feed.

Live, slaughter and ham traits

The electronic feeder identified the animal and amount of feed eaten in each feeding bout, and individual feed intake was calculated on a daily basis. Individual BW was measured at 2-week intervals using an electronic scale. The data obtained were used to calculate individual GR (kg/d) and feed conversion ratio (FCR). When the average weight of pigs in the batch reached 165 kg, all the pigs were transported to a commercial abattoir, where they were slaughtered. At carcass processing, the main commercial lean (neck, loin, shoulder and ham) and fat cuts (backfat, belly and jowl) from both halves of each carcass were weighed. After a 24-h chilling period (0–2 °C), green hams were dressed, and weight of dressed green hams (DRHAM) was taken. A skilled operator assessed the thickness of subcutaneous fat on each left DRHAM below the biceps femoris at the level of the femur head (Bosi & Russo 2004) using a ruler. The same operator visually scored each left DRHAM for round shape (0 = low, to 4 = high), lean colour (−4 = very pale to 4 = very dark), bicolour (0 = absent to 4 = very evident), haemorrhages (0 = absent to 4 = very evident), veining (0 = absent to 4 = very evident), marbling (0 = absent to 4 = very evident) and fat cover thickness (−4 = very thin to 4 = very thick), as described by Gallo et al. (2016). A sample of subcutaneous fat, including both the outer and inner layer, was collected from each left green ham during trimming and used for assessing iodine value (Wijs method, AOAC 2003) and fatty acid methyl esters using an Agilent 7820 A gas chromatographer (Agilent, Palo Alto, CA). Details of the lipid analysis can be found in Gallo et al. (2016). The DRHAM were processed according to the San Daniele PDO protocol (MIPAAF 2007), and the hams were weighed after ripening (358 ± 10 d after arrival).

Data editing and statistical analysis

Seven pigs were removed from the trial due to death or injuries, so the data on live, carcass and raw thigh traits were drawn from the records of 233 pigs. During sorting for PDO compliance, 36 dressed hams were discarded, so the data on ham weight and processing losses were obtained from the records of 430 hams from 225 pigs. When both hams of a pig were processed, ham weights were averaged prior to statistical analysis, otherwise the weight of a single processed ham was used.

Before statistical analysis, records were classified according to GR quartile from the beginning to the end of the trial. Calculation of the quartiles was based on the residual standard deviation of GR estimated by analysis of variance with a mixed model that included the effects of the factors taken into account in the experimental design of the previous feeding trial, namely diet, batch, sex, pen within (diet × batch) and diet × sex interaction (Gallo et al. 2014). As an exploratory analysis revealed GR to be significantly related to
the BW at the beginning of the trial \( (p < .001) \), BW was included as a covariate in the model used to calculate the GR quartiles. The data were then analysed using the MIXED procedure of SAS with the same model used in the calculation of the GR quartiles, with no covariate and with the addition of the effect of GR quartile. Polynomial contrasts were estimated to investigate the relationships between GR quartile and live performance, carcass and raw thigh traits. The first-order comparisons measured linear relationships, while the second- and third-order comparisons measured quadratic and cubic relationships, respectively.

A coefficient of variation (CV), a measure of relative variation useful for comparing different traits or groups with different mean values, was calculated within the GR quartiles for BW and DRHAM and used as a description of uniformity (Alfonso et al. 2010).

### Results and discussion

The genetic line used in this study is specifically intended for Italian heavy pig production, with selection placing greater emphasis on ham quality traits than on GR (Sturaro et al. 2008; Schiavon et al. 2015). The GR of finishing pigs in the current trial averaged 666 g/d, a value only slightly greater than the GR reference value (650 g/d) reported for Italian heavy pigs (BPEX 2016; CRPA 2015). However, the CV of GR was close to 14%, and the variation gave rise to clearly different quartiles for average GR (from 578 to 748 g/d, Table 1), even after adjustment for initial BW, with an average interquartile difference in GR ranging from 40 to 70 g/d, equal to 0.44–0.77 standard deviation units, and a maximum difference between the average GR in the bottom and the top quartiles of 170 g/d, equal to 1.86 standard deviation units.

The main live and carcass traits were all influenced by GR quartile (Table 1). A preliminary exploratory analysis showed average BW at the beginning of the trial to have an inverse relationship with the GR during the finishing period, and progressively decreased as the GR quartile increased, ranging between 98 for pigs in the bottom quartile and 83 kg in the top (data not shown in table). This suggests that during the finishing phase there is some kind of compensatory growth, which has been described as a physiological response of accelerated final GR in which pigs that have undergone a limitation in their growth, for instance experiencing a period of reduced feed intake, may compensate when normal feeding is restored (Lebret 2008; Douglas et al. 2013). The pigs in this study were born and reared on the same farm and fed the same diet under the same feeding regime until they were transferred to the finishing herd. During finishing, the pigs were fed on a restricted feeding scale using feeding stations configured to provide each pig with the planned restricted amount of feed per day. However, as the minimum amount of feed released by the station was 200 g per meal, pigs could consume more feed than planned if they had consumed less than the planned amount for that day during their previous visits (Schiavon et al. 2015). On the contrary, some pigs may have consumed less feed than the allotted during the trial. Some degree of individual variation in feed intake was, therefore, possible, even within the restricted feeding regime, and actual average daily feed intake increased linearly with GR quartile (Table 1, \( p < .001 \)). Nevertheless, the inclusion of initial BW as covariate in the statistical model used for calculating the quartiles made it possible to adjust the pig classification for initial BW, so that comparisons of the effects of different GR quartiles can be made under comparable initial BW (Table 1).

### Table 1. Least squares means of the growth rate (GR) quartile on body weight, feed conversion ratio and main carcass traits of finishing Italian heavy pigs.

| GR quartile | 1 | 2 | 3 | 4 | SEM | p Value | Linear | Quadratic | Cubic |
|-------------|---|---|---|---|-----|---------|--------|-----------|-------|
| Average growth rate, g/d | 578 | 648 | 688 | 748 |     |         |        |           |       |
| N | 58 | 59 | 58 | 58 |     |         |        |           |       |
| Body weight, kg | | | | | | | | | |
| Beginning | 90 | 93 | 94 | 91 | 1.44 | .24 | | | |
| End | 156 | 167 | 171 | 177 | 0.75 | <.001 | <.001 | .01 | .08 |
| Feed intake, g/d | 2473 | 2569 | 2667 | 2757 | 16.41 | <.001 | <.001 | .34 | .35 |
| Feed conversion, g/g | 4.33 | 4.05 | 3.92 | 3.67 | 0.05 | <.001 | <.001 | .76 | .26 |
| Carcass weight, kg | 126 | 137 | 141 | 145 | 0.63 | <.001 | <.001 | .01 | .09 |
| Backfat thickness, mm | 29.4 | 31.1 | 32.3 | 32.8 | 0.52 | <.001 | <.001 | .28 | .89 |
| Total lean cuts: | | | | | | | | | |
| Weight, kg | 69.24 | 73.78 | 75.38 | 77.15 | 0.49 | <.001 | <.001 | .01 | .17 |
| Proportion on carcass weight, % | 54.21 | 54.00 | 53.61 | 53.26 | 0.25 | .03 | .002 | .77 | .86 |
| Total fat cuts: | | | | | | | | | |
| Weight, kg | 23.17 | 25.37 | 26.41 | 27.29 | 0.29 | <.001 | <.001 | .03 | .48 |
| Proportion on carcass weight, % | 18.09 | 18.56 | 18.79 | 18.86 | 0.20 | .02 | .003 | .32 | .94 |
Final BW increased as GR quartile increased according to both linear and quadratic trend, and differences in final BW resulted in differences in carcass traits of similar trend and magnitude. Therefore, carcass weight and the weights of total lean and fat cuts in pigs in the top quartile was nearly 13, 12 and 17% greater, respectively, than pigs in the bottom quartile, and nearly 6, 5 and 8% greater, respectively, than pigs in the second quartile, in which average GR was close to the current benchmark value for Italian heavy pigs. Despite their lower final BW, pigs in the bottom GR quartile (Figure 1) exhibited a nominally greater CV of BW than pigs in the other quartiles (5.3 versus 3.2–3.8%, the lowest value being for pigs in the top GR quartile), evidence of a tendency towards lower uniformity in BW, an important quality attribute in pig production (Alfonso et al. 2010).

The increase in GR improved linearly the FCR ($p < .001$), with pigs in the top GR quartile consuming on average 6, 9 and 15% less feed per unit of gain than those in the 3rd, 2nd and bottom quartiles, respectively. The feed conversion ratio is an economically crucial factor in various production systems (Serenius et al. 2007; Hermesch et al. 2014), and improvements in feed conversion are of paramount importance to pig producers. The increase in GR was associated with a linear decrease in the proportion of lean cuts and with a linear increase in the proportion of fat cuts. These results agree with data obtained by Correa et al. (2006), who reported that carcasses of fast growing pigs were fatter than those of more slowly growing ones.

As previously observed with respect to the weight of carcasses and commercial cuts, DRHAM weight also increased linearly as the GR quartile increased (Table 2, $p < .001$). Moreover, the DRHAM from pigs in the slowest growing category also tended to show greater variation in weight, with a CV of 7.2% compared with 4.6–5.9% for the DRHAM from pigs in the other quartiles (Figure 2). There is an increasing demand for uniformity not only in pig weight, but also in the size and weight of carcasses and retailed cuts (Merks et al. 2012). This is particularly important for the dry-cured-ham industry, as the amount of salt used and the duration of salting depend on the weight of the dressed hams (Laureati et al. 2014).

Subcutaneous fat thickness of DRHAM tended to increase as the GR quartile increased ($p = .06$), and pigs of the 3rd and 4th GR quartiles yielded DRHAM with a greater subcutaneous fat thickness than DRHAM from pigs in the 2nd quartile (by 7%) and bottom quartile (by 12%). Correa et al. (2006) also found that fast growing pigs had a thicker fat cover on the ham compared with slowly growing pigs, and Yang et al. (2012) reported thicker backfat in high GR than low GR pigs. Ham adiposity is considered a critical trait for seasoning aptitude, as increased ham fat cover has been associated with lower seasoning losses and enhanced sensorial properties in the dry-cured ham (Bosi & Russo 2004; Candek-Potokar & Skrlep 2012). In fact, seasoning losses were affected by GR quartile ($p < .05$), and exhibited a linear decrease as average GR increased, with a nearly 3% reduction in seasoning losses in dry-cured hams from the pigs in the top quartile compared with those in the bottom quartile. Producers are concerned about low DRHAM fat cover, one of the main reasons for hams being discarded from PDO status at the slaughterhouse and the ham factory, and the problem may be getting worse as the selection of pigs for improved farm performance and carcass leanness is changing the genetic background of animals (Lo Fiego et al. 2005). A way of alleviating this critical problem may be to increase the target GR of heavy pigs, which means increasing BW at slaughter at the same time, given the required minimum age of 9 months at slaughter.

The fatty acid composition of DRHAM subcutaneous fat was not affected by differences in the GR of pigs, even though saturated fatty acids (SFA) tended to increase and polyunsaturated fatty acids (PUFA) nominally tended to decrease as GR quartile increased. The fatty acid composition of covering fat seems to be associated more with BW at slaughter than with GR. Lo Fiego et al. (2010) found greater proportion of SFA and lower proportion of PUFA in the covering fat of heavy pigs slaughtered at 160 kg BW than in that of pigs intended for fresh meat consumption and slaughtered at 90 kg BW. Conversely, in a trial dealing with heavy pigs slaughtered at the same age but at different BW, Lo Fiego et al. (2005) found no differences in

![Figure 1. Coefficient of variation of final body weight of pigs according to the growth rate quartile during finishing.](image-url)
the fatty acid composition of pigs at average final BW of 164 and 176 kg, whereas the subcutaneous fat of pigs slaughtered at an average BW of around 150 kg had fewer SFA and more PUFA.

Visual appraisal of DRHAM is commonly used to sort green hams at the slaughterhouse and the ham factory, in order to predict processing quality and to detect fresh thighs defects (Pinna et al. 2015; Gallo et al. 2016). Candek-Potokar and Skrlep (2012) reported that differences in age and weight at slaughter may affect quality traits of green hams, but there is little information available about direct relationships between GR and the characteristics of green hams. In our study, the GR quartile of pigs only affected the visual appraisal scores of round shape and marbling of DRHAM (p < .05). Namely, as the GR quartile increased the scores of roundness increased linearly, whereas those of marbling decreased linearly. Yang et al. (2012) also reported that fast growing pigs yielded fatter carcasses but lower marbling score of longissimus dorsi than slowly growing pigs slaughtered at the same age. On the contrary, Nissen et al. (2009) found that differences in the GR of pigs of similar age and weight at slaughter did not influence fresh meat quality traits, and Correa et al. (2006) found no effects of GR on meat quality traits.

As a result of heavier DRHAM and lower seasoning losses, the weight of dry-cured ham increased linearly with GR quartile (p < .001), and dry-cured hams from pigs in the top quartile were nearly 3, 6 and 12% heavier than pigs in the 3rd, 2nd and bottom quartiles, respectively.

**Conclusions**

In the traditional management of heavy pigs for PDO dry-cured ham production, a moderate growth rate is aimed to attain a BW of around 160 kg BW at 9 months of age, assuming that in such conditions the carcasses and meat of the pigs will reach a degree of maturity.
that gives the green hams good seasoning aptitude. However, effective selection schemes and improved feeding techniques have greatly enhanced the growth rate potential of modern pigs, and this could be exploited, at least partially, to face increasing production costs. The results of this study indicate that increasing the GR of finishing heavy pigs from around 580 g/d to around 750 g/d may improve the feed conversion efficiency and subcutaneous fat coverage of green hams and the weight of dry-cured hams with a mainly linear trend, and may reduce seasoning losses without influencing subcutaneous fat composition and some other technological properties of green hams. Therefore, even within the PDO scenario, increasing the target growth rate by adjusting the feeding protocols to new targets could be a way of improving the income of pig producers and also improving some quality traits of raw hams. An average GR of 750 g/d resulted in better overall performance than lower GR, ranging from 580 to nearly 700 g/d, and could be adopted as a target during the finishing phase of heavy pigs from roughly 90 to 100 kg BW upwards. A consequence of increasing the growth rate within a constrained age is the concomitant increase in weight at slaughter, and further research is needed to assess the effects of these proposals on the dry-cured ham production chain.

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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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