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Abstract

Data from our previous experiment were used to model the chemical growth of 323 pigs raised under non-limiting environmental and feeding conditions. The study assessed the pigs' metabolizable energy (ME) and standardized ileal digestible (SID) lysine requirements. In addition, the effects of restricting feed and SID lysine intake on growth and nutrient requirements were examined. The pigs arrived at the testing facility weighing 89 ± 12 kg at 142 ± 3 d of age. One group was fed high-protein diets *ad libitum* until 8 to 9 months old, while the other two groups were fed medium or low-protein diets, restricted by approximately 20%, until they reached 170 kg at 9 months or older. Live weight and backfat depth were measured repeatedly to estimate individual empty body weight, body protein, and lipid masses at various ages. The data were fitted using the Gompertz growth model, and ME and SID lysine requirements were estimated for pigs older than 150 d, based on literature. The average mature protein mass of the *ad libitum*-fed pigs was 38.7 kg, with a maximum potential protein gain of 183 g/day at 140 d of age. The mature lipid mass was 115 kg, with a maximum potential lipid gain of 385 g/day at 216 d, and a lipid-to-protein ratio of 2.96 at maturity. Based on our findings, for pigs with a similar genetic background raised for dry-cured ham production, we recommend reducing dietary SID lysine levels from 7.33 to 3.23 g/kg as age increases from 150 to 270 d, assuming a feed intake of 2.91–3.30 kg/day. Both feed and protein restrictions exerted significant impacts, with all growth parameters consistently diminishing in proportion to the level of imposed dietary nutrient restriction. The recommended dietary SID lysine levels for pigs subjected to dietary nutrient restriction feed-restricted pigs were similar to those found in ad libitum-fed pigs, and both were significantly lower than the industry standards typically used in feed formulations.

Keywords: Pig, Gompertz growth curves; Nutrient requirements; SID-lysine; Feed restriction.

Introduction

Dry-cured ham production is a common practice in many countries, particularly those with a strong tradition of cured meat product [1]. The demand for high-quality artisanal products continues to challenge the dry-cured ham industry by requiring mature pigs with sufficient fat covering on carcasses and hams [2,3]. On the other hand, improved genotypes are often considered too lean for dry-cured ham production, making farmers slaughter pigs at heavier weights and older ages or resort to fatter local unimproved pig genotypes [4]. In certain production systems, pigs are fed restrictively with low-protein diets to reduce environmental impact and slow their growth, based on the assumption that hams from older pigs develop better seasoning qualities [5]. In addition, the growing genetic diversity among pig breeds, combined with the complexity of production practices, has led to a limited knowledge of the characteristics of pig populations used in dry-cured ham production systems, especially regarding nutrient requirements of such pigs at heavier weights and older ages. Curves age-related for body protein (BP) and body lipid (BL) can be used to establish the energy and protein requirements of different pig breeds [6,7]. However, restrictive factors like high ambient temperatures, air humidity, poor health, and insufficient nutrient allowances can limit growth. As a result, the innate growth potential of a specific pig genotype can only be accurately assessed using data from pigs raised in non-restrictive conditions [8].

In our recent experiment, 424 pure Goland C21 barrows and gilts were fed diets either exceeding or falling short of their requirements for SID lysine - the first limiting indispensable amino acid. The diets were provided either *ad libitum* or with restricted feeding [9,10]. These data were used to model the chemical growth of pigs raised under both non-restrictive and restrictive conditions. We hypothesized that restrictive feeding affects the growth curve parameters, depending on the nature and degree of restriction applied. Therefore, understanding these curves is essential for describing the chemical growth of Goland C21 pigs, determining their energy and protein requirements, developing strategies to manipulate their body composition, improving carcass and ham quality at slaughter, and reducing resource waste and environmental impact of dry-cured ham heavy pig production systems.

The objective of this study, therefore, was to model the chemical growth of the Goland C21 pig population under non-restrictive feeding and ambient conditions, elucidate the impact of traditional feeding restrictions, and estimate the metabolizable energy (ME) and SID lysine requirements for heavy pigs intended for high-quality dry-cured ham production.

Materials and Methods

Animal ethics statement

The data employed in this study were obtained from a previous trial [9], which investigated the impact of alternative rearing strategies on animal growth performance, carcass characteristics, and the quality of hams designated for PDO dry-cured ham production. In detail, the study involved both *in vivo* and *ex vivo* measurements taken from 424 purebred Goland C21 barrows and gilts, all offspring of 23 sires. The experiment was approved by the Animal Ethics Committee of the University of Padova (document #36/2018) and complied with the European Union Directive on animal experimentation [11].

Animal rearing

At the beginning of each rearing batch (a total of 4 batches), the pigs that arrived (from 96 to 112 pigs, depending on the batch) were housed in 8 pens, in a variable number depending on the batch (12 to 14 pigs/pen), provided with automated feeding systems (Compident Pig MLP, Schauer Agrotronic, Prambachkirchen, Austria). Each pen contained both barrows and gilts and was balanced for sex and live weight (LW). After six d of acclimation, the experiment started at an average pig's weight of 93.6 ± 8.8 kg LW and age of 148 ± 1 day. The experiment was arranged as a split-plot design with treatment and sex within a pen, applying four treatments: one conventional and three alternative rearing strategies (2 pens per rearing strategy). Two groups had *ad libitum* access to the same high-protein diet (ALHP; 162 to 138 g/kg CP with increasing age). The first of these groups, defined as younger age, reached the target weight of 170 kg at approximately 8 months of age. In contrast, the second subgroup, defined as greater weight, reached the target age of 9 months and was slaughtered at a greater LW than the other groups. In the present study, these first two groups were merged. The remaining two groups were fed a traditional diet under restricted feeding conditions until they reached the target LW of 170 kg. The third group (referred to as RMP, restricted medium protein) was fed a diet with a medium protein content (128 to 119 g/kg CP with increasing age) and reached the target weight at nine months of age. The fourth group (referred to as RLP, restricted low protein) was fed a low protein diet (113 to 104 g/kg CP with increasing age) and reached the target weight after nine months of age.

The high-protein feeds used during the early and late finishing for the ALHP group were formulated to ensure non-limiting energy and essential amino acid supplies, in line with NRC [7] guidelines. The SID lysine content of the medium-protein diet, reflecting the traditional diet commonly used in practice, was approximately 27% lower than the NRC [7] recommendations for the corresponding LW range. Additionally, the low-protein feeds were formulated to contain approximately 50% less lysine than the NRC [7] reference, and care was put into ensuring lysine was the first limiting amino acid. A comprehensive description of the feeds used in this study is reported by Schiavon et al. [10]. The key characteristics of experimental treatments are outlined in Table 1. The experiment was designed to raise the pigs in the ALHP treatment under non-restrictive conditions while subjecting the RMP group to dietary energy restriction and the RLP group to both energy and amino acid restriction. Feed restriction amounted to approximately 20% for both the RMP and RLP treatments [10].

The pigs from the three batches were raised during the autumn, winter, and spring seasons, with the average room temperature consistently measured at 20.4 ± 1.8 °C, and relative humidity averaging 55.7 ± 30.6%. The pigs from the fourth batch were raised during the hot summer season, characterized by room temperatures exceeding 30°C for an extended period. These pigs showed a marked reduction in feed intake and growth compared to those in the other batches. To avoid bias in the growth curves due to the effects of the hot summer season, all pigs from this batch were excluded from the analysis. Additionally, during the trial, 10 pigs were moved to the infirmary due to lameness, and one pig died from gastric torsion. Data from these animals was also excluded from the analysis. After these exclusions, a total of 323 pigs were included in the study, consisting of 159 pigs in the ALHP group, 81 pigs in the RMP group, and 83 pigs in the RLP group.

Data collection and computation of body composition

The pigs were weighed using an electronic scale at the beginning and end of the trial, as well as every 2-3 weeks interval. Backfat depth (BF), in mm, was measured at similar intervals using an A-mode ultrasonic device (Renco Lean-Meater series 12, Renco Corporation, Minneapolis, MN, USA). The BF measurements were taken approximately 5 to 8 cm from the midline at the last rib. On average, each pig had 8.8 ± 1.54 observations for LW and 5.1 ± 1.26 observations for BF. These repeated individual measures of LW and BF were utilized to estimate empty body, protein, and lipid masses in heavy pigs at various ages. Empty body mass (EBM) was estimated as described by Kloareg et al [12]:

$$\mathrm{EBM} = 0.914 \times \mathrm{LW}^{1.008}$$

Body lipid (BL) and protein (BP) masses were estimated as [13,14]:

$$\mathrm{BL, kg} = \frac{9.17 + (0.7 \times \mathrm{BF})}{100} \times \mathrm{LW}$$

$$\mathrm{BP, kg} = 0.1353 \times (\mathrm{EBM} - \mathrm{BL})^{1.1175}$$

The parameters of the individual growth curves were determined using the unified non-linear Gompertz model described by Tjørve and Tjørve [15], utilizing all data available for each pig. The functional form of the model was as follows:

$$y_{t_i} = \ln(\mathrm{W}_{0_i}) + \ln\left(\frac{\mathrm{W}_{m_i}}{\mathrm{W}_{0_i}}\right) \times \left[1 - \mathrm{e}^{\left(-\frac{\mathrm{e} \times \mathrm{GR}_{\mathrm{U}_i} \times \mathrm{age}_{t_i}}{\mathrm{Wm}}\right)}\right]$$

where y_{t_i} is the log-transformed value of EBM, BL, or BP of individual *i* at time t; W_0 was the initial mass value (of EBM, BL, or BP) at age 0 (kg); W_m was the upper asymptotic mass value (of EBM, BL, or BP, in kg); $\mathrm{GR}_{\mathrm{Ui}}$ was the absolute maximum growth rate (kg/d), that occurs at the curve inflexion point, and age_{t_i} was the age (d) of the pig at time t.

A set of additional parameters were computed for a better characterization of the pigs:

The age at the inflexion point (t_i at GR_U) was achieved as:

$$\mathrm{t_i \ at \ GR_{U_i}} = \frac{\ln\left(-\ln\left(\frac{W_0}{Wm}\right)\right)}{e \cdot \frac{GR_{U_i}}{Wm}}$$

The potential absolute growth rate (kg/d) at various ages was computed as:

$$\mathrm{GRt} = W_0 \cdot \ln\left(\frac{W_0}{Wm}\right) \cdot -\left(\frac{-e \cdot GR_U}{Wm} \cdot e^{\left(\frac{-e \cdot GR_U \cdot t}{Wm}\right)}\right) \cdot e^{\ln\left(\frac{Wm}{W_0}\right) \cdot \left(1 - e^{\left(\frac{-e \cdot GR_U \cdot t}{Wm}\right)}\right)}$$

The dimensionless maturing rate constant B for BP was obtained as:

$$B = GRt_i / \left(Wt_i \cdot \left(\ln\left(\frac{Wm_i}{Wt_i}\right)\right)\right)$$

Computation of metabolizable energy and SID Lysine requirements

The individual Gompertz curves for EBM, BL and BP were plotted to estimate the instantaneous growth rate of EBM, BL (GR_{BL}), and BP (GR_{BP}) from 10 to 300 d of age. The final age of 270 d is indicated by the current product specifications for the high-quality dry-cured ham production in Italy as a minimal age at slaughter [16,17].

The ME requirement for maintenance (MEm), lipid, and protein gain was computed according to NRC [7] as:

$\mathrm{MEm, MJ/d} = 0.824 \ \mathrm{LW}^{0.60} + 52.30 \times GR_{BL} + 44.35 \times GR_{BP}$

Similarly, the requirement of SID Lysine for maintenance and growth ($\mathrm{SID\text{-}Lys_{rqm}}$, g/d) was computed according to NRC [7] as follows:

$\mathrm{SID\text{-}Lys_{rqm}} = [(\text{feed intake} \times 0.88 \times 0.417) \times 1.1 + 4.5/1000 \times \mathrm{LW}^{0.75}]/0.75$

In the equation above, 0.88 is the dry matter content of the feed, and 0.75 is the marginal efficiency of using the SID-lysine for maintenance. In NRC [7], the marginal efficiency is further adjusted to consider the difference between the maximum protein deposition of the pig population compared to the standards for gilts, barrows, and entire males. We ignored this adjustment because it would have very little negative impact on the total SID-lysine requirements:

$\mathrm{SID\text{-}Lys_{rqg}}$ as: $GR_{BP} \times 0.071/0.648 \times 1000$

Regarding the equation for the requirement of SID Lysine for growth, the marginal efficiency of SID-Lys utilization for protein deposition was not adjusted for LW but was considered constant, in accordance with Van Milgen et al. [6] and Schiavon et al. [10]. In particular, the value of 0.648, indicated in NRC [7] for growing pigs of 50 kg LW, close to the level reported by Schiavon et al. [10] on C21 Goland heavy pigs fed medium protein diets, was used for calculation. The expected feed intake was computed by dividing the estimated ME requirement for a representative dietary ME content of 12.40 MJ/kg, and the proposed dietary SID-lysine content as the daily SID-Lys requirement/expected feed intake.

Statistical analysis

The individual Gompertz curves were fitted using the function nlsLM of the package minpack.lm (version 1.2-4) of the R software (version 4.2.3) [18]. The fitting was completed by assuming that the empty body, protein, and lipid masses at birth were 0.93, 0.11, and 0.094 kg, respectively, for all the pigs [19]. These values were representative of the piglets born at the Goland C21 genetic center.

The curve parameters and all the other estimated variables were analyzed using the lmer package within the R software [18] using the following linear mixed model:

$y_{ijklm} = \mu + T_i + sex_j + (T \times sex)_{ij} + batch_k + pen(T \times batch)_{l:ik} + e_{ijklm}$

where y_{ijklm} was the observed trait, μ was the overall intercept of the model, T was the fixed effect of the ith treatment (i = 1, . . . , 3), sex was the fixed effect of the jth sex (j: 1 = gilts, 2 = barrows), (T × sex) was the interaction effect between treatment and sex, batch was the random effect of the kth batch (k = 1, . . . , 3), pen was the random effect of the lth pen within the $(batch \times T)_{ik}$ interaction (l = 1, 2), and e_{ijklm} was the random residual.

The pen, the batch, and the residuals were assumed to be independently and normally distributed with a mean of zero and variance σ^2k, σ^2l, and σ^2e, respectively. The effect of treatment was tested on the pen (T × batch) variance, whereas sex and the T × sex interaction were tested on the residual variance.

Treatments were subjected to multiple comparisons using the Bonferroni correction.

Results

Descriptive statistics

The descriptive statistics of the parameters for modelling the Gompertz curves are presented in Table 2. The data demonstrated a good fit, with an average R-squared value exceeding 0.99 and low residual standard deviations across all dependent variables. The mature EBM (EBM_m) varied between 159 and 313 kg, with an average of 216 kg and a coefficient of variation of 17%. The maximum potential growth rate of EBM ($GR_{U\text{-}EB}$) averaged 0.979 kg/day, with values ranging from 0.744 to 1.228 kg/day. The average age at $GR_{U\text{-}EB}$ was 140 d, with a range spanning from 101 to 188 d.

The average mature body protein (BP_m) mass was approximately 36 kg, with a 13% coefficient of variation and estimates ranging from 26 to 49 kg. The average maximum protein growth rate ($GR_{U\text{-}BP}$) was around 170 g/day, with a 10% coefficient of variation. The age at $GR_{U\text{-}BP}$ was estimated to be 134 d, varying from 96 to 179 d. The maturing rate constant (B) averaged 0.013, ranging from 0.010 to 0.017.

The mature body lipid (BL_m) mass averaged 89 kg, with a wide range from 46 to 210 kg and a variation coefficient of 45%. The maximum body lipid mass growth rate ($GR_{U\text{-}BL}$) averaged 320 g/day, with a variation coefficient of 30%. The $GR_{U\text{-}BL}$ was typically attained at an average age of 195 d, with a variation coefficient of 19.5%. The BL:BP ratio at maturity ranged from 1.20 to 5.10, with an average of 2.40 and a variation coefficient of 38%.

Factors of variation of the Gompertz curves parameters

Table 3 provides the least square means (LSM) and *p*-values for the main factors of variation of the Gompertz curve parameters. The curve parameters were strongly influenced by the treatment while showing minimal or no influence by sex and treatment × sex interaction. As expected, the standard error of the mean (SEM) values was consistently low.

Both RMP and RLP feeds resulted in significantly lower values of the EBM_m curve parameters compared to the ad libitum treatment ($p < 0.001$). Pigs fed with ALHP feeds exhibited an average mature EBM_m of 246 kg, with a $GR_{U\text{-}EB}$ exceeding 1.0 kg/day achieved at approximately 150 d. Significant differences were also observed between RLP and RMP ($p = 0.019$), with RLP treatment yielding the lowest values for the Gompertz parameters and RMP falling in between ALHP and RLP. Figure 1 illustrates the variation of EBM with increasing age, while Fig. 2 depicts the EBM growth rate.

A similar pattern was observed for the BP_m constituent, with pigs receiving ALHP exhibiting greater value compared to other treatments ($p < 0.001$). Significant differences between RLP and RMP were also noted ($p < 0.001$), albeit quantitatively lower than those observed between them and the ALHP treatment. Compared to RMP, RLP evidenced a lower BP_m mass (31.2 vs 34.4 kg, $p = 0.003$), slightly lower $GR_{U\text{-}EB}$ (161 vs 169 g/day, $p = 0.009$), and a lower age at $GR_{U\text{-}EB}$ (125 vs 132 d, $p = 0.047$), with no difference for the maturing rate parameter. Figure 3 illustrates the graphical representation of the variation of BP with increasing age, while Fig. 4 provides the BP growth rate.

The greatest differences among treatments were observed in the BL_m. A significant difference was noted between ALHP and the other two treatments ($p < 0.001$), with only numerical differences observed between RMP and RLP that received the same feed allowance. Specifically, with the ALHP treatment, the BL_m mass was approximately double that of the other two treatments (116 kg vs 65.6 and 61.1 kg, respectively, $p < 0.001$), with the maximum $GR_{U\text{-}BL}$ 60% greater (385 vs 240 g/day, $p < 0.0001$), and the age at $GR_{U\text{-}BL}$ 22% greater (216 vs 176 d, $p < 0.0001$). As a result, the BL:BP ratio at maturity was 52% greater (2.96) in the ALHP treatment compared to the mean of the other two treatments (1.94). Figure 5 provides the graphical representation of the variation of BL with increasing age, while Fig. 6 depicts the BL growth rate.

Estimates of the metabolizable energy and SID lysine requirements

Table 4 presents the *p*-values and the estimates for LW, BP, BL, and protein and lipid gain from 150 to 270 d of age. Significant differences between treatments were consistently observed ($p < 0.01$), with the highest values recorded for the ALHP group, intermediate values for the RMP group, and the lowest values for the RLP group. At the traditional slaughter age of 270 d, ALHP pigs were estimated to have 200 kg LW, containing 31.9 kg of BP and 59.8 kg of BL, with protein and lipid growth rates of 77 g/day and 336 g/day, respectively. Under feed restriction, RMP pigs at the same age were estimated to weigh 172 kg, with 29.1 kg of BP and 44.4 kg of BL, growing protein and lipid at rates of 63 g/day and 174 g/day, respectively. Lastly, the RLP pigs at 270 d old were estimated to have a LW of 163 kg, with 27.1 kg of BP and 41.6 kg of BL, and protein and lipid growth rates of 51 g/day and 161 g/day, respectively.

There were little differences in the estimated ME requirement (Table 5) between RLP and RMP treatments with increasing ages, but significant differences were found between them and ALHP (p <0.001). The ME requirement of the ALHP pigs were always greater than 36 MJ/d, with a peak of 42.0 MJ/d at 240 d of age, at about 180 kg LW. The ME requirements of the other two groups were about 20% lower than ALHP, with a peak of 33.7 MJ/d for RMP and 31.9 MJ/d for RLP, both observed at 180 d of age, and 120 - 116 kg LW, respectively. The computed SID lysine requirements decreased from 21.2 to 10.5 g/d with the ALHP, from 19.3 to 8.46 g/d for RMP, and from 17.8 to 7.06 g/d for RLP, the differences among treatments were always highly significant at $p < 0.001$. Nevertheless, despite the differences in predicted feed intake across the treatments, variations in the required dietary standardized ileal digestible (SID) content among treatments were minimal. Hence, the estimated SID lysine feed content decreased from an average value of 7.33 g/kg at 150 d of age to an average value of 3.27 g/kg at 270 d of age, irrespective of the treatment.

Discussion

The potential growth of body constituents

A pig reaches its full growth potential under non-restrictive feeding and optimal production management, assuming that the dietary nutrient supply is adequately balanced from birth to maturity [8]. Under these ideal conditions, the pig can fully express its growth potential, particularly in terms of BP, water, and ash components. According to Emmans' theoretical model [20], it is also possible to achieve targeted lipid growth, but this requires precise dietary protein-to-energy ratios. If the pig's diet lacks sufficient amino acids, the animal will compensate by consuming more feed, leading to an excess energy intake, which is subsequently stored as lipids in adipose tissue [21]. This results in a higher body lipid-to-protein ratio (BL:BP), indicating a poorly formulated diet and an undesirable increase in fat deposition. On the other hand, when pigs are provided with a diet containing excess protein, they prioritize fulfilling their maintenance energy requirements first, followed by potential protein deposition, and finally, lipid growth. Only in this latter scenario, energy intake is consistent with the pig's genetic predisposition for fatness [20]. Modern lean pig genotypes generally have a low mature body lipid-to-backfat ratio, which results in lower feed intake and a reduced propension to accumulate fat [22]. This characteristic makes them less suitable for the production of dry-cured ham [16, 17].

The Goland C21 pigs utilized in this study are widely used in Italy to produce offspring for traditional dry-cured ham production systems [23]. In these systems, a strict feed restriction of approximately 20% is typically applied, using either medium- or low-protein diets [24,25]. This led to the initial question: does the Goland C21 genetic line have a great inherent potential for both lean and fat tissue growth when raised under optimal feeding and environmental conditions? To address this, data from the batch raised during the hot summer season were excluded, following the theoretical considerations outlined above. Instead, data from the remaining three batches were analyzed, as these pigs were reared in seasons where ambient temperatures were maintained between 15 to 20°C. The ALHP feed was specifically formulated to exceed the protein and essential amino acid requirements [10], and data from any pigs exhibiting health issues were excluded from the analysis. Consequently, the growth observed in the ALHP pigs was considered to be sufficiently representative of potential and desired BP and BL deposition.

Gompertz growth model and limitation of current estimates

The Gompertz growth curves for various pig populations have been extensively estimated in the past, providing a basis for calculating nutritional requirements throughout their growth phases [26–28]. In this study, the data fitting to the Gompertz model was satisfactory and comparable with previous research findings [29–31].

Among the different mathematical models used to describe growth, the Gompertz function is particularly valuable because it predicts the growth potential of each chemical component using three biologically meaningful parameters: EBM_m, B, and the inflection point of the curve (t*), which represents the time at which GR_U is achieved [32].

Several reparameterizations of the Gompertz function have been developed to adapt the model for different datasets and to improve the comparability of results. For example, in the unified Gompertz model proposed by Tjørve and Tjørve [15], the growth rate parameter provides an absolute growth rate, in contrast to the relative growth rate indicated by the B constant in the original formulation. Most growth models prioritize protein as the key variable since other body components can be estimated based on their allometric relationships with protein [32,33].

Despite the good fit of the experimental data to the Gompertz curves, there are some limitations to the growth curves generated in this study. Firstly, the estimation of BP and BL masses relied on a method that involved repeated measurements of individual body weight (BW) and backfat thickness (BFT). This approach assumes that these simple body measurements are reliable indicators of overall body composition in pigs [34]. In a previous performance test study involving 920 C21 Goland pigs, Schiavon et al. [13] demonstrated that repeated measurements of BW and BFT could effectively estimate changes in body composition, with the resulting feed intake estimates showing a high correlation (RSD = 0.046 kg, $R^2 = 0.961$) with measured feed intake data. These results support the reliability of this method for estimating variations in BL and BP masses in the C21 Goland pigs used in the current study.

Secondly, the pigs in this study entered the experimental facility at approximately 150 and 90 kg LW, with limited data available from their earlier growth stages. These pigs originated from the Goland C21 genetic line nucleus, suggesting that they were likely raised under optimal conditions that promoted favorable growth rates. However, the absence of data from the earlier growth period could have affected the accuracy of the estimated parameters for the growth curves, introducing uncertainty, particularly in the early growth phase. Consequently, nutrient requirements for younger pigs were not reported in the current study.

The chemical growth of the C21 Goland pigs.

The existing literature shows considerable variation in the parameters of the Gompertz growth curve across different pig breeds, with substantial differences observed between local and modern lean pig genotypes [4,35]. Typically, unimproved pig breeds tend to have BP_m ranging from 32 to 38 kg, with B values between 0.0095 and 0.0105. This leads to a $GR_{U\text{-}BP}$ of about 115 to 145 g/day, with the lowest rates observed in castrated males, intermediate rates in gilts, and the highest in entire males [36]. Consistent with these findings, average protein gains of less than 100 g/day have been reported in many local pig populations [4]. In contrast, pigs that have undergone intensive selection for lean growth can exhibit BP_m exceeding 50 kg, with B values between 0.0125 and 0.0135, resulting in significantly higher $GR_{U\text{-}BP}$, ranging from 220 to 260 g/day [36,37]. Information on the ideal lipid-to-protein ratios at maturity is limited, mainly due to the challenges associated with providing diets with optimal protein-to-energy ratios. However, the literature suggests that unimproved pig breeds tend to have mature lipid-to-protein ratios greater than 4.0, whereas improved pig genotypes typically exhibit a ratio around 2.0 [36,38], or even lower [39].

In this study, the ALHP C21 Goland pigs showed an average BPm of 38.7 kg, with a mean B of 0.0129, and a $GR_{U\text{-}BP}$ of 183 g/day. The age at which these pigs reached their $GR_{U\text{-}BP}$ was approximately 140 d, about 10 d before the pigs arrive at the experimental facility. Additionally, these pigs exhibited a BL_m of nearly 89 kg, with a $GR_{U\text{-}BL}$ of 315 g/day occurring at about 195 d of age, resulting in a mature lipid-to-protein ratio of 2.96.

The EBM growth curve indicated a $GR_{U\text{-}EB}$ of 1.053 kg/day at an age of 150 d. These findings suggest that the growth potential of the Goland C21 pigs is intermediate between that of unimproved and highly improved pig breeds, aligning with the selection goals for this genetic line, which focus on moderate increases in lean growth and feed efficiency while emphasizing the quality of thighs for dry-cured ham production [23,40].

The observed BL: BP for this genetic line appears sufficient to achieve adequate fat coverage of the carcass and thighs at slaughter. However, if market demands require, a slight reduction in dietary protein supply could potentially stimulate a higher voluntary feed intake, leading to increased fatness and a subsequent decrease in the lean-to-fat ratio of the pig [21].

Feed restriction, particularly when associated with protein restriction, had a significant impact on the growth curve parameters. Our findings indicate that restricting feed and using medium or low-protein diets significantly reduced the EBM_m and the $GR_{U\text{-}EB}$, BP_m and BL_m. The most pronounced effect of feed restriction was observed on the lipid component, with a nearly 50% reduction in estimated BL_m and a decrease in $GR_{U\text{-}BL}$ by 44% to 48%. Additionally, the

BP_m decreased by 12% to 20%, and the $GR_{U\text{-}BP}$ reduced by 8% to 11% compared to pigs fed *ad libitum*. These results suggest that traditional feed restriction practices may be nutritionally inefficient for dry-cured ham production in modern lean pig populations. In addition, our results revealed that protein restriction, combined with overall feed restriction, did not result in a greater partitioning of dietary energy toward fat synthesis, contrary to previous assumptions [24]. This suggests that the strategy of limiting protein intake does not necessarily enhance fat deposition in pigs, highlighting the need to reconsider these traditional feeding practices in the context of modern lean pig genetics.

The nutrient needs of the C21 Goland pigs

Based on the growth curves developed in this study, at 150 d of age, the ALHP pigs were projected to consume approximately 2.91 kg of feed per day, delivering 36.1 MJ/day of ME and 21.2 g/day of standardized ileal digestible (SID) lysine, which equates to 7.33 g of SID lysine per kilogram of feed. When compared to the average pig data from the NRC [7] at a similar weight, the Goland C21 pigs in this study were estimated to exhibit a 21% greater growth rate, consume 11% more feed, and have a 15% greater daily SID lysine requirement, while maintaining a comparable dietary SID lysine concentration (7.3 g/kg for NRC versus 7.33 g/kg for the Goland C21 pigs). These results align with recent literature [41–43], which suggests that the daily SID lysine requirement of modern growing pigs is higher than those recommended by the NRC [7], largely due to an enhanced potential for protein deposition of modern pig genotypes [44].

For early grower pigs at approximately 90 kg LW with an average protein gain of 112 g/day, Van Milgen et al. [6] reported an estimated SID lysine requirement of around 4.9-5.0 g/kg of feed or 12.9 g/day. The ratios of the SID lysine requirement to daily protein gain from the NRC [7] and Van Milgen et al. [6] data were calculated to be 0.130 and 0.115, respectively. The corresponding value from this study was 0.119, which is closer to Van Milgen et al.'s findings. The slightly higher value compared to the NRC [7] can be attributed to the assumption of a marginal efficiency of SID lysine utilization of 0.648, in contrast to the maximum marginal efficiency of 0.72 assumed in the InraPorc model [6].

For pigs exceeding 140 kg LW, there is limited data available for direct comparison, as most nutritional guidelines typically address requirements up to 135-140 kg LW [7,45,46]. The findings of the present study suggest that when fed ad libitum, Goland C21 pigs continue to demonstrate substantial potential for both lean and fat growth even at these higher weights. At 270 d of age, their anticipated feed intake remains above 3 kg/day, although the dietary SID lysine content decreases to approximately 3.1 g/kg of feed.

From a practical standpoint, this indicates that as these pigs age and their LW increases, the proportion of protein-rich ingredients in their diet can be gradually reduced, with cereals becoming the primary feed component during the later stages of the growing-fattening phase. For example, the typical SID lysine content in grains such as barley, corn, wheat, and wheat bran are around 3.0, 1.9, 2.9, and 3.8 g/kg, respectively, whereas soybean meal averages a much higher 26.3

g/kg [7]. This shift towards higher cereal inclusion aligns with the decreased lysine requirements as pigs approach their mature weight, optimizing feed costs without compromising growth performance.

Nutrient partitioning when the pigs are fed restricted

The expected feed intake for the ALHP pigs during the early finishing phase (150-180 d) and late finishing phase (180-270 d) averaged 3.08 and 3.33 kg/day, respectively. These estimates were in line with the observed feed intakes of 2.93 and 3.45 kg/day for the corresponding periods. This confirms that the nutrient requirements predicted from the Gompertz growth curves and the NRC [7] model are accurate for heavy pigs fed ad libitum. In contrast, pigs under restricted feeding conditions (RMP and RLP) had expected feed intakes of 2.59 to 2.52 kg/day for the early and late finishing phases, while the actual intakes were 2.51 to 2.79 kg/day, respectively. Notably, during the late finishing period, these pigs consumed about 11% more feed than predicted. This discrepancy indicates that under restricted feeding conditions, heavy pigs might convert dietary ME less efficiently for maintenance and growth than predicted by the NRC [7] model.

The ME requirements for heavy pigs, as derived from the NRC [7] equation, may not be sufficiently accurate since the original data were based on studies with pigs of lower LW. If the MEm is recalculated using Crovetto et al.'s [47] formula for heavy pigs (MEm = 441 kJ/LW^0.75), the requirement for a 180 kg LW pig would be about 17% higher than the value estimated by the NRC model. This adjustment suggests that the predicted feed intake for RLP pigs could be around 10% higher, aligning more closely with the observed values during the experiment.

The predicted daily SID lysine requirements for RMP pigs were estimated to decrease from 18.2 g/day in the early finishing phase to 12.64 g/day in the late finishing phase, whereas the observed intakes were 15.6 and 14.4 g/day, respectively. Similarly, for RLP pigs, the SID-Lys$_{\mathrm{rqm}}$ ranged from 16.6 g/day in the early finishing period to 10.9 g/day in the late finishing period, with measured intakes of 11.4 and 9.8 g/day. The discrepancies in lysine intake, particularly during the early finishing phase, might be partially explained by the assumption of marginal efficiency of SID lysine utilization of 0.648 [7], which may not be appropriate when pigs receive a restricted diet.

Overall, these findings suggest that, based on the growth curves under traditionally restricted feeding conditions, the dietary SID lysine content for heavy pigs should be significantly lower than the levels (> 6 g/kg) commonly used in commercial feeds. This adjustment could lead to a more precise formulation of diets, optimizing the nutrient efficiency for heavy pigs in restricted feeding scenarios.

The application of the Gompertz growth curve model provided a reliable framework for estimating the nutritional needs and growth potential of pigs raised for dry-cured ham production, confirming its suitability for both lean and fat tissue development predictions. Our findings demonstrated that pigs fed *ad libitum* exhibited greater feed intake and nutrient efficiency, with superior protein and lipid growth rates compared to those under restricted feeding. In addition, Goland C21 genetic line demonstrates a balanced potential for both protein and lipid growth, making it well-suited for the production of high-quality Italian dry-cured ham. This pig genetic line's growth characteristic lies between those of local unimproved breeds and modern lean genotypes, indicating its adaptability for producing heavier hams with better fat covering ideal for the dry-cured ham industry. To optimize growth potential of pigs intended for dry-cured ham production, our recommendation is to apply a feeding strategy that includes a feed intake of 2.91–3.30 kg/day and a gradual reduction in dietary SID lysine content from 7.33 to 3.23 g/kg with increasing age from 150 to 270 d. Furthermore, the study highlights that feed restriction significantly impacts growth performance, reducing both protein and lipid gains in proportion to the degree of the restriction applied. However, discrepancies in the predicted versus observed feed intake and lysine requirements in restricted pigs suggested that existing nutritional models may underestimate the energy needs of heavier pigs under restrictive conditions. As such, restricted pigs tend to be leaner and less efficient than pigs fed *ad libitum*, suggesting a need to re-assess traditional feeding methods to enhance growth outcomes for heavy pigs destined for dry-cured ham production.

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Tables and Figures

Table 1. Experimental treatment features of the experimental groups.

Main treatments	Fed ad libitum high protein diet (ALHP[2])		Fed restricted (RMP[2])	Fed restricted (RLP[2])
Subgroups	Younger age	Greater weight	Medium protein diets	Low protein diets
Target weight at slaughter, kg	170	170	> 170	170
Target age at slaughter, d	< 270	270	270	>270
Experimental period duration, d	82 ± 12	105 ± 10	105 ± 10	118 ± 13
Starting age	148 ± 3		148 ± 3	148 ± 3
Initial live weight, kg	93.9 ± 12		93.1 ± 12	93.6 ± 12
Final live weight, kg	180.9 ± 15		172.7 ± 15	169.1 ± 15
Initial backfat thickness	12.1 ± 3.5		12 ± 3.4	12.2 ± 3.5
Final backfat thickness	24.1 ± 4.1		24.8 ± 4.2	21.4 ± 4.2
Feeds in early finishing[1] (90-120 kg LW)				
Feed intake, kg/d	2.931		2.494	2.517
Metabolizable Energy, MJ/kg	13.4		13.2	13.2
Net Energy, MJ/kg	10.0		10.0	10.1
Crude protein, g/kg	162		128	113
Lysine, g/kg	8.3		6.2	4.5
Methionine, g/kg	2.7		2.0	1.8
Cysteine, g/kg	3.0		2.6	2.3
Threonine, g/kg	5.7		4.3	3.6
Tryptophan, g/kg	2.0		1.5	1.2
Tyrosine, g/kg	5.3		4.1	3.6
Valine, g/kg	7.6		5.9	5.1
SID lysine, g/kg	7.4		5.4	3.8
Feeds in late finishing[1] (120 kg LW onwards)				
Feed intake, kg/d	3.449		2.798	2.787
Metabolizable Energy, MJ/kg	13.4		13.2	13.1
Net energy, MJ/kg	10.1		10.0	9.9
Crude protein, g/kg	138		119	104
Lysine, g/kg	6.9		5.2	3.5
Methionine, g/kg	2.2		1.9	1.7
Cysteine, g/kg	2.8		2.4	2.2
Threonine, g/kg	4.9		3.8	3.4
Tryptophan, g/kg	1.7		1.3	1.1
Tyrosine, g/kg	5.4		4.2	3.6
Valine, g/kg	6.7		5.5	4.9
SID lysine, g/kg	5.9		4.5	2.9

[1] Dietary content are expressed as-fed basis.

[2] ALHP = pigs fed under ad libitum conditions high-protein diets, up to 170 kg body weight (younger age subgroup), or up to 9 months of age (greater weight subgroup); RMP = pigs fed under restricted conditions with a medium-protein diets up to 170 kg body weight and 9 months of age; RLP = pigs fed under restricted conditions with a low-protein diets up to 170 kg body weight and more than 9 months of age.

Table 2. Descriptive statistics of Gompertz growth curve[1] parameters for empty body, body protein and lipid masses of 323 pure C21 Goland pigs.

Traits[2]	Mean	SD	CV	P 0.1	P 99
Empty body mass:					
EBM_m, kg	216	37	17.1	159	313
$GR_{U\text{-}EB}$, kg/d	0.979	0.112	11.2	0.744	1.228
Age at $GR_{U\text{-}EB}$, d	140	19	13.6	101	188
R^2	1.000	<0.001	0.023	0.999	1.000
RMSE, kg	0.026	0.011	43.7	0.006	0.055
Protein:					
BP_m, kg	35.7	4.7	13.1	26.3	49.0
$GR_{U\text{-}BP}$, kg/d	0.174	0.017	10.0	0.133	0.211
Age at $GR_{U\text{-}BP}$, d	134	16	11.9	96	179
B	0.013	0.001	10.8	0.010	0.017
R^2	1.000	<0.001	0.014	0.999	1.000
RMSE, kg	0.030	0.016	53.5	0.002	0.069
Lipid:					
BL_m, kg	88.7	39.7	44.9	46.2	210.2
$GR_{U\text{-}BL}$, kg/d	0.315	0.098	30.6	0.191	0.613
Age at $GR_{U\text{-}BL}$, d	195	38	19.5	127	296
R^2	1.000	<0.001	0.041	0.998	1.000
RMSE, kg	0.060	0.031	51.0	0.006	0.135
Lipid to protein ratio at maturity	2.43	0.90	37.5	1.22	5.10

[1] Based on newborn piglet weights collected at the Goland genetic centre, it was assumed that the empty body, protein and lipid masses at birth were 0.93, 0.11, and 0.094 kg, respectively. Curves were developed by fitting measures (live weight) or estimates (body protein and lipid mass) performed on individual pigs from about 148 d of age and 93 kg live weight. The physiological mature mass of each body constituent is estimated as the asymptote of Gompertz curve, which represents the point at which the daily gain of the defined body constituent becomes zero. Caution must be used for the estimates produced by these curves for LW lower than 90 kg and age < 150 d.

[2] EBM_m = Empty body mass at physiological maturity; $GR_{U\text{-}EB}$ = Absolute maximum growth rate of empty body mass; BP_m = Body protein mass at physiological maturity; $GR_{U\text{-}BP}$ = Absolute maximum growth rate of body protein mass; B = maturing rate constant for body protein mass; BL_m = Body lipid mass at physiological maturity; $GR_{U\text{-}BL}$ = Absolute maximum growth rate of body lipid mass; RMSE = Root Mean Square Error.

Table 3. Least-square means for the rearing treatments and *p*-values of the factors of variation of the Gompertz growth curve parameters of 323 pure C21 Goland pigs.

Item[1]	Treatment[2]			SEM[3]	*p*-values			RMSE[4]
	ALHP	RMP	RLP		Treatment	Sex	Treatment × sex	
Observations	159	81	83					
Empty body:								
EBM_m, kg	246^{a}	196^{b}	181^{c}	3.2	< 0.001	0.226	0.006	20.5
$GR_{U\text{-}EB}$, kg/d	1.053^{a}	0.925^{b}	0.888^{c}	0.009	< 0.001	< 0.001	0.418	0.071
Age at $GR_{U\text{-}EB}$, d	150^{a}	133^{b}	127^{b}	1.5	< 0.001	0.019	0.394	11.8
Body protein:								
BP_m, kg	38.7^{a}	34.4^{b}	31.2^{c}	0.5	< 0.001	0.661	0.777	3.1
$GR_{U\text{-}BP}$, kg/d	0.183^{a}	0.169^{b}	0.161^{c}	0.002	< 0.001	0.066	0.859	0.012
Age at $GR_{U\text{-}BP}$, d	140^{a}	132^{b}	125^{c}	1.6	< 0.001	0.108	0.994	11.3
B	0.0129^{b}	0.0134^{ab}	0.0140^{a}	0.0002	< 0.001	0.032	0.839	0.0009
Body lipid:								
BL_m, kg	116^{a}	65.6^{b}	61.1^{b}	3.7	< 0.001	0.393	0.726	29
$GR_{U\text{-}BL}$, kg/d	0.385^{a}	0.257^{b}	0.240^{b}	0.009	< 0.001	0.224	0.356	0.066
Age at $GR_{U\text{-}BL}$, d	216^{a}	177^{b}	176^{b}	3.3	< 0.001	< 0.001	0.792	28.8
Lipid to protein ratio at maturity	2.96^{a}	1.92^{b}	1.97^{b}	0.09	< 0.001	0.384	0.715	0.73

[1] EBM_m = Empty body mass at physiological maturity; $GR_{U\text{-}EB}$ = Absolute maximum growth rate of empty body mass; BP_m = Body protein mass at physiological maturity; $GR_{U\text{-}BP}$ = Absolute maximum growth rate of body protein; B = maturing rate constant for body protein mass; BL_m = Body lipid mass at physiological maturity; $GR_{U\text{-}BL}$ = Absolute maximum growth rate of body lipid mass. The physiological mature mass of each body constituent was estimated as the asymptote of Gompertz curve which represents the point at which the daily gain of that body constituent becomes zero.

[2] ALHP = pigs fed under ad libitum conditions high-protein diets (162 to 138 g/kg crude protein (CP) with increasing age), up to 170 kg body weight (younger age subgroup), or up to 9 months of age (greater weight subgroup); RMP = pigs fed under restricted conditions with a medium-protein diets (128 to 119 g/kg CP with increasing age) up to 170 kg body weight and 9 months of age; RLP = pigs fed under restricted conditions with a low-protein diets (113 to 104 g/kg CP with increasing age) up to 170 kg live weight and more than 9 months of age.

[3] SEM = pooled standard error of the mean.

[4] RMSE = Root Mean Square Error.

[a – c] Within a row, values with different superscripts differ significantly ($p < 0.05$).

Table 4. Least-square means and *p*-values of potential growth and body constituents at increasing age computed from the Gompertz growth curve parameters of pure C21 Goland pigs according to the different feeding strategies[1].

Item	Age, d				
	150	180	210	240	270
Live weight, kg					
ALHP	96^{a}	127^{a}	156^{a}	180^{a}	200^{a}
RMP	94^{ab}	120^{b}	142^{b}	159^{b}	172^{b}
RLP	92^{b}	116^{b}	136^{c}	152^{c}	163^{c}
SEM[2]	0.87	0.97	1.08	1.25	1.53
p-value	0.005	< 0.001	< 0.001	< 0.001	< 0.001
Body protein mass, kg					
ALHP	16.1^{a}	21.2^{a}	25.6^{a}	29.2^{a}	31.9^{a}
RMP	15.6^{ab}	20.2^{b}	23.9^{b}	26.9^{b}	29.1^{b}
RLP	15.4^{b}	19.5^{b}	22.8^{c}	25.3^{c}	27.1^{c}
SEM[2]	0.165	0.172	0.192	0.221	0.268
p-value	0.007	< 0.001	< 0.001	< 0.001	< 0.001
Body lipid mass, kg					
ALHP	18.4^{a}	28.1^{a}	38.9^{a}	49.5^{a}	59.8^{a}
RMP	17.4^{ab}	24.9^{b}	32.1^{a}	38.7^{b}	44.4^{b}
RLP	16.4^{b}	23.4^{c}	30.2^{c}	36.3^{b}	41.6^{b}
SEM[2]	0.27	0.38	0.54	0.70	1.00
p-value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Protein gain, kg/d					
ALHP	178^{a}	160^{a}	132^{a}	103^{a}	77^{a}
RMP	162^{b}	141^{b}	113^{b}	86^{b}	63^{b}
RLP	149^{c}	125^{c}	96^{c}	71^{c}	51^{c}
SEM[2]	1.7	2.5	2.9	2.7	2.3
p-value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Lipid gain, kg/d					
ALHP	296^{a}	342^{a}	361^{a}	358^{a}	336^{a}
RMP	240^{b}	248^{b}	234^{b}	206^{b}	174^{b}
RLP	225^{b}	232^{b}	218^{b}	192^{b}	161^{b}
SEM[2]	4.2	5.9	8.7	10.6	12.0
p-value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

[1] ALHP = pigs fed under ad libitum conditions high-protein diets (162 to 138 g/kg crude protein (CP) with increasing age), up to 170 kg body weight (younger age subgroup), or up to 9 months of age (greater weight subgroup); RMP = pigs fed under restricted conditions medium-protein diets (128 to 119 g/kg CP with increasing age) up to 170 kg body weight and 9 months of age; RLP = pigs fed under restricted conditions low-protein diets (113 to 104 g/kg CP with increasing age) up to 170 kg body weight and more than 9 months of age. All data represent the means derived from the projections of the individual Gompertz growth curves for body constituents.

[2] SEM = pooled standard error of the mean.

$^{a-c}$ Within a row, values for each Gompertz growth curve parameter with different superscripts differ significantly ($p < 0.05$).

Table 5. Least-square means and *p*-values of the predicted metabolizable energy requirements, expected feed consumption, and standardized ileal digestible (SID) lysine requirement at increasing age of pure C21 Goland pigs according to the different feeding strategies[1].

Item	Age, d				
	150	180	210	240	270
Metabolizable energy[2], MJ/d					
ALHP	36.1^{a}	40.2^{a}	41.9^{a}	42.0^{a}	40.9^{a}
RMP	32.3^{b}	33.7^{b}	33.3^{b}	31.8^{b}	30.0^{b}
RLP	30.7^{c}	31.9^{c}	31.4^{b}	29.9^{b}	28.2^{b}
SEM[3]	0.29	0.38	0.55	0.69	0.79
p-value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Expected feed intake[4], kg/d					
ALHP	2.91^{a}	3.24^{a}	3.38^{a}	3.38^{a}	3.30^{a}
RMP	2.61^{b}	2.72^{b}	2.69^{b}	2.57^{b}	2.42^{b}
RLP	2.48^{c}	2.57^{c}	2.53^{b}	2.41^{b}	2.27^{b}
SEM[3]	0.023	0.031	0.045	0.056	0.063
p-value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
SID lysine[5], g/d					
ALHP	21.2^{a}	19.5^{a}	16.5^{a}	13.4^{a}	10.5^{a}
RMP	19.3^{b}	17.1^{b}	14.0^{b}	11.0^{b}	8.46^{b}
RLP	17.8^{c}	15.3^{c}	12.2^{c}	9.35^{c}	7.06^{c}
SEM[3]	0.19	0.28	0.33	0.33	0.27
p-value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
SID lysine feed content, g/kg feed					
ALHP	7.33	6.04	4.92	3.99	3.23^{ab}
RMP	7.45	6.29	5.23	4.29	3.49^{a}
RLP	7.22	5.94	4.81	3.87	3.1^{b}
SEM[3]	0.07	0.09	0.10	0.10	0.09
p-value	0.096	0.046	0.035	0.038	0.028

[1] ALHP = pigs fed under ad libitum conditions high-protein diets (162 to 138 g/kg crude protein (CP) with increasing age), up to 170 kg body weight (younger age subgroup), or up to 9 months of age (greater weight subgroup); RMP = pigs fed under restricted conditions medium-protein diets (128 to 119 g/kg CP with increasing age) up to 170 kg body weight and 9 months of age; RLP= pigs fed under restricted conditions low-protein diets (113 to 104 g/kg CP with increasing age) up to 170 kg body weight and more than 9 months of age. All data represent the means derived from the projections of the individual Gompertz growth curves for body constituents.

[2] Metabolizable energy requirements were computed as: $0.824 \times LW^{0.6} + 44.35 \times$ Protein gain $+ 52.3 \times$ Lipid gain [7].

[3] SEM = pooled standard error of the mean.

[4] Computed as (ME requirements/dietary ME content), assuming dietary ME contents of 12.40 MJ/kg.

[5] The SID lysine requirements were computed according to NRC [7]. For maintenance the equation was: [feed consumption (kg) $\times 0.88 \times 0.417 \times 1.1 + 4.5/1000 \times LW^{0.75}$]/0.75. For growth the equation was: Protein gain $\times$ 0.071/0.648 (g/d).

[a – c] Within a row, values for each Gompertz growth curve parameter with different superscripts differ significantly ($p < 0.05$).

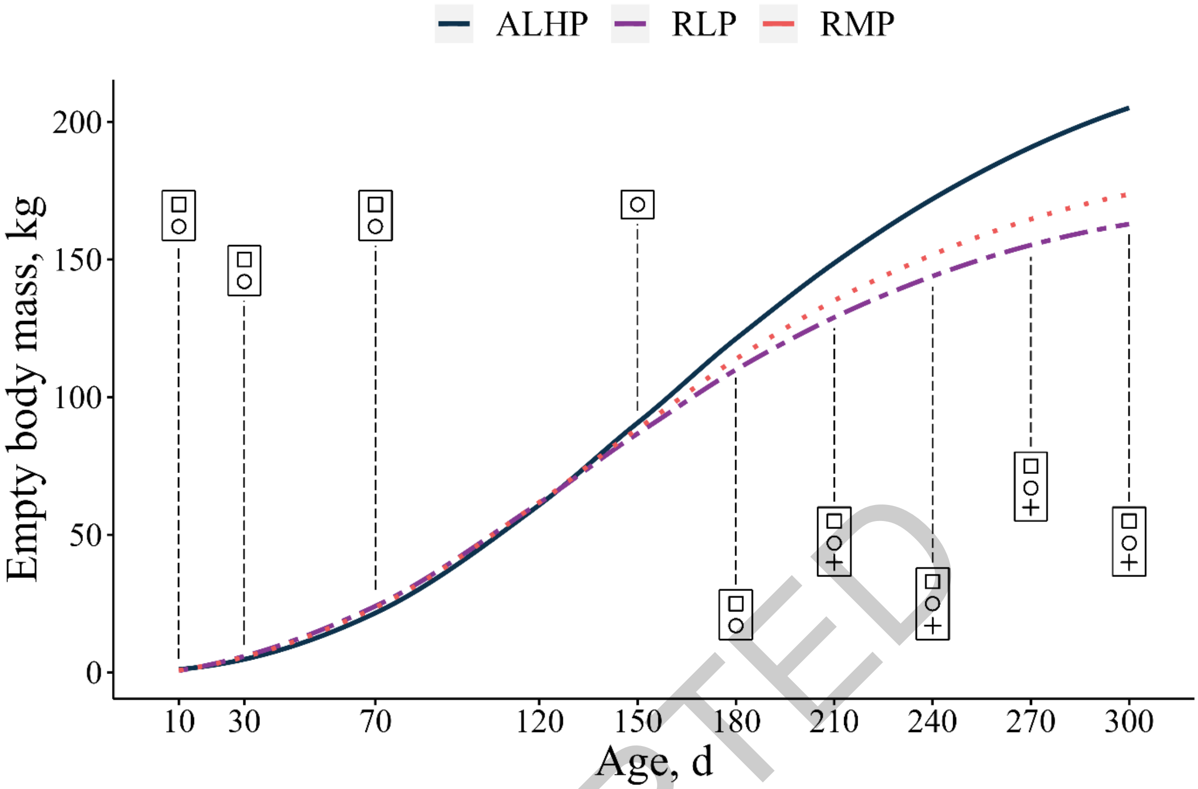

Fig. 1. Least square means for mature mass. Statistically significant contrasts ($p < 0.05$) are reported in the figure using the following symbols: □ ALHP vs RMP; ○ ALHP vs RLP; + RMP vs RLP.

ALHP = pigs fed under ad libitum conditions high-protein diets (162 to 138 g/kg crude protein (CP) with increasing age), up to 170 kg body weight (younger age subgroup), or up to 9 months of age (greater weight subgroup); RMP = pigs fed under restricted conditions medium-protein diets (128 to 119 g/kg CP with increasing age) up to 170 kg body weight and 9 months of age; RLP= pigs fed under restricted conditions low-protein diets (113 to 104 g/kg CP with increasing age) up to 170 kg body weight and more than 9 months of age.

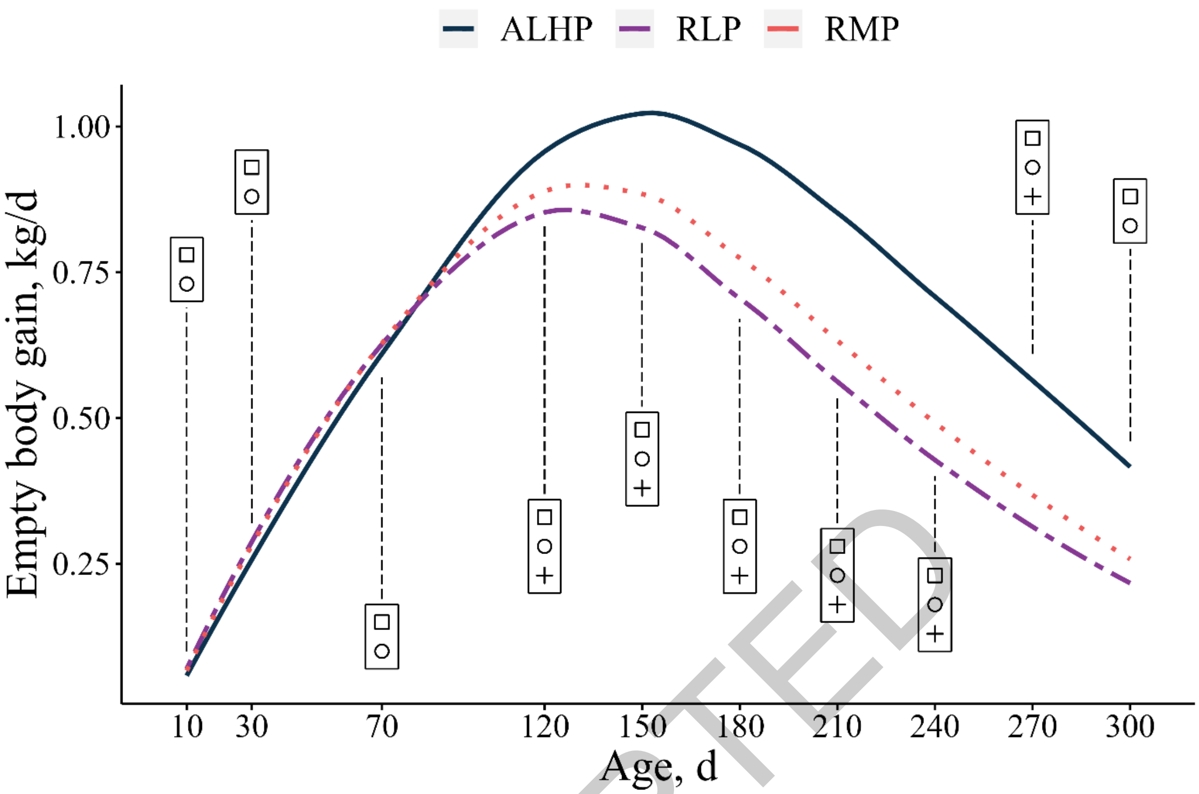

Fig. 2. Least square means for potential daily gain. Statistically significant contrasts ($p < 0.05$) are reported in the figure using the following symbols: □ ALHP vs RMP; ○ ALHP vs RLP; + RMP vs RLP.

ALHP = pigs fed under ad libitum conditions high-protein diets (162 to 138 g/kg crude protein (CP) with increasing age), up to 170 kg body weight (younger age subgroup), or up to 9 months of age (greater weight subgroup); RMP = pigs fed under restricted conditions medium-protein diets (128 to 119 g/kg CP with increasing age) up to 170 kg body weight and 9 months of age; RLP= pigs fed under restricted conditions low-protein diets (113 to 104 g/kg CP with increasing age) up to 170 kg body weight and more than 9 months of age.

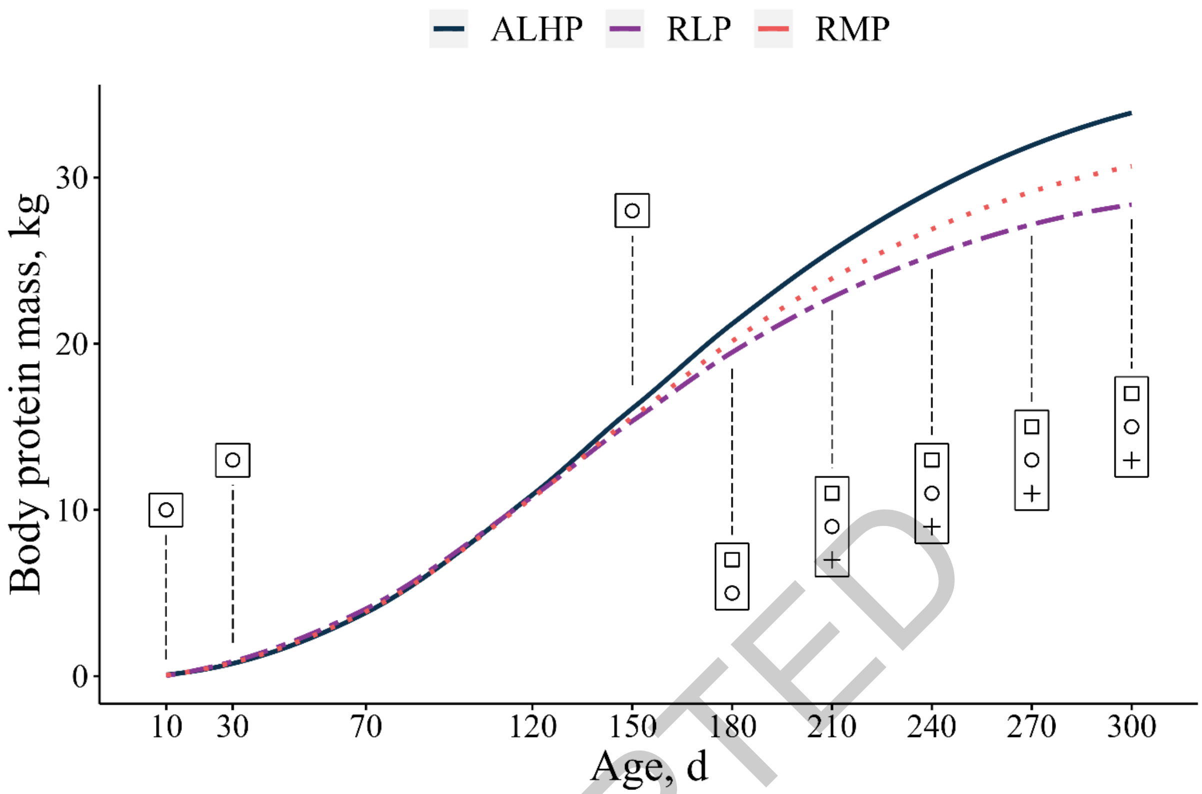

Fig. 3. Least square means for mature protein mass. Statistically significant contrasts ($p < 0.05$) are reported in the figure using the following symbols: □ ALHP vs RMP; ○ ALHP vs RLP; + RMP vs RLP.

ALHP = pigs fed under ad libitum conditions high-protein diets (162 to 138 g/kg crude protein (CP) with increasing age), up to 170 kg body weight (younger age subgroup), or up to 9 months of age (greater weight subgroup); RMP = pigs fed under restricted conditions medium-protein diets (128 to 119 g/kg CP with increasing age) up to 170 kg body weight and 9 months of age; RLP= pigs fed under restricted conditions low-protein diets (113 to 104 g/kg CP with increasing age) up to 170 kg body weight and more than 9 months of age.

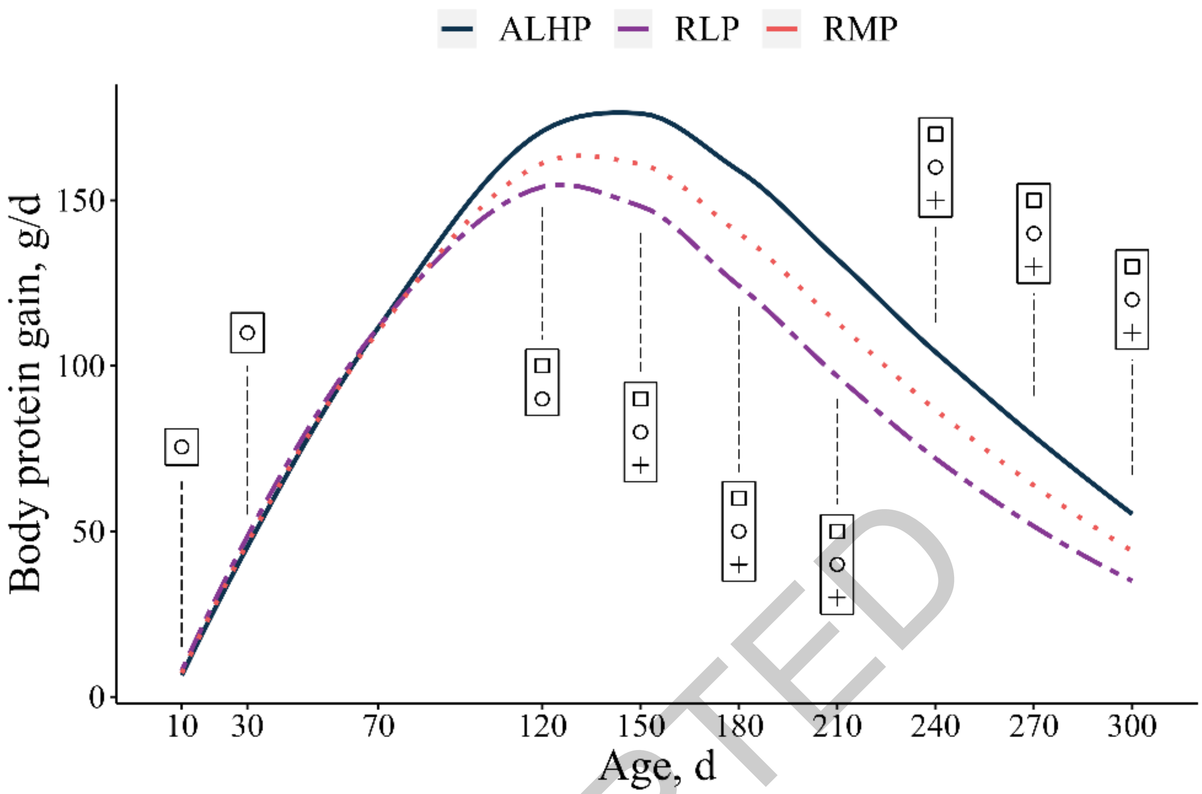

Fig. 4. Least square means for potential protein gain. Statistically significant contrasts ($p < 0.05$) are reported in the figure using the following symbols: □ ALHP vs RMP; ○ ALHP vs RLP; + RMP vs RLP.

ALHP = pigs fed under ad libitum conditions high-protein diets (162 to 138 g/kg crude protein (CP) with increasing age), up to 170 kg body weight (younger age subgroup), or up to 9 months of age (greater weight subgroup); RMP = pigs fed under restricted conditions medium-protein diets (128 to 119 g/kg CP with increasing age) up to 170 kg body weight and 9 months of age; RLP= pigs fed under restricted conditions low-protein diets (113 to 104 g/kg CP with increasing age) up to 170 kg body weight and more than 9 months of age.

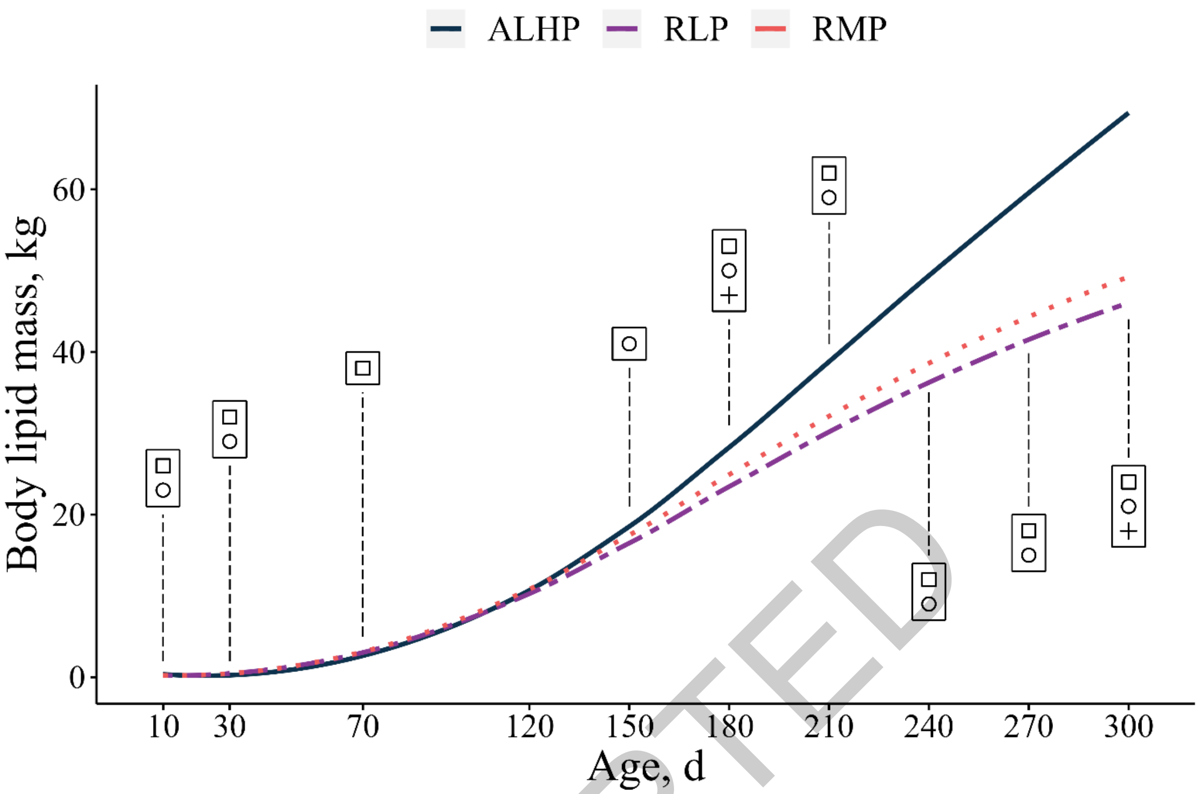

Fig. 5. Least square means for mature lipid mass. Statistically significant contrasts ($p < 0.05$) are reported in the figure using the following symbols: □ ALHP vs RMP; ○ ALHP vs RLP; + RMP vs RLP.

ALHP = pigs fed under ad libitum conditions high-protein diets (162 to 138 g/kg crude protein (CP) with increasing age), up to 170 kg body weight (younger age subgroup), or up to 9 months of age (greater weight subgroup); RMP = pigs fed under restricted conditions medium-protein diets (128 to 119 g/kg CP with increasing age) up to 170 kg body weight and 9 months of age; RLP= pigs fed under restricted conditions low-protein diets (113 to 104 g/kg CP with increasing age) up to 170 kg body weight and more than 9 months of age.

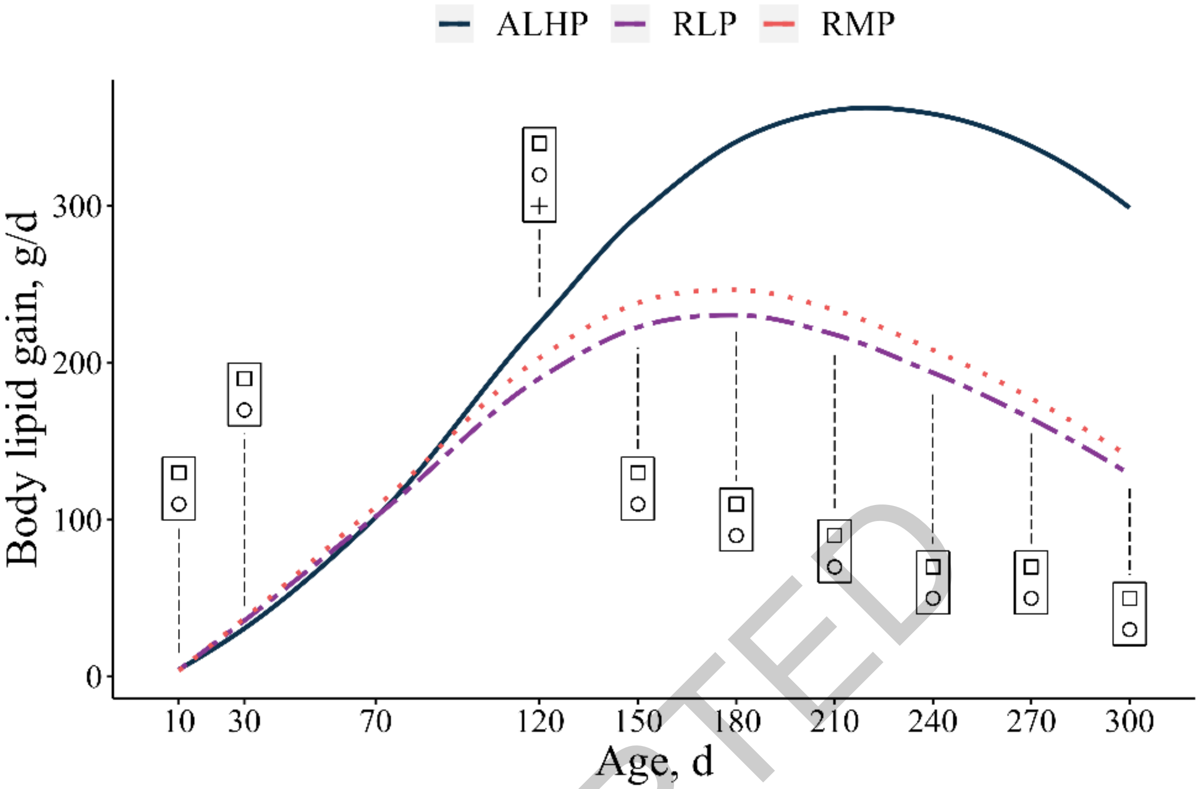

Fig. 6. Least square means for potential lipid gain. Statistically significant contrasts ($p < 0.05$) are reported in the figure using the following symbols: □ ALHP vs RMP; ○ ALHP vs RLP; + RMP vs RLP.
ALHP = pigs fed under ad libitum conditions high-protein diets (162 to 138 g/kg crude protein (CP) with increasing age), up to 170 kg body weight (younger age subgroup), or up to 9 months of age (greater weight subgroup); RMP = pigs fed under restricted conditions medium-protein diets (128 to 119 g/kg CP with increasing age) up to 170 kg body weight and 9 months of age; RLP = pigs fed under restricted conditions low-protein diets (113 to 104 g/kg CP with increasing age) up to 170 kg body weight and more than 9 months of age.