ANIMAL SCIENCE (ZOOTECNIA)

Agrária —Revista Brasileira de Ciências Agrárias
ISSN (on line) 1981-0997
v.21, n.2, a4394, 2026
Recife, PE, UFRPE. www.agraria.pro.br
DOI: 10.5039/agraria.v21i2a4394 - Protocol 4394
Subm. 04/09/2025 • App. 08/05/2026 • Pub. 21/05/2026

Growth dynamics and tissue partitioning in surgically and immunocastrated pigs: insights from Gompertz modeling and allometric analysis

Henrique da Costa Mendes Muniz[1*], Caroline Flores Soares[1], Deise Dalazen Castagnara[1], Oussama Tej[2], Rodrigo Soares Volpatto[3], Marrone da Silva dos Santos[3]

1 Universidade Federal do Pampa, Uruguaiana, RS, Brasil. E-mail: henriquemuniz@unipampa.edu.br; carolineflores.aluno@unipampa.edu.br; deisecastagnara@unipampa.edu.br
2 Institut de Recerca i Tecnologia Agroalimentàries, Constantí, Tarragona, Spain. E-mail: oussama.tej@irta.cat
3 Universidade Federal de Santa Maria, Santa Maria, RS, Brasil. E-mail: rodrigovolpatto97@gmail.com; marrone.s.santos@gmail.com

ABSTRACT: Immunocastration has been proposed as an alternative to surgical castration because of its effects on growth performance and carcass composition in pigs. This study evaluated growth curves and tissue deposition patterns in surgically castrated (SC) and immunocastrated (IM) male pigs using Gompertz and allometric models. Growth curve parameters and tissue deposition were estimated using nonlinear regression procedures, and allometric coefficients for protein and lipid deposition relative to body weight were evaluated. IM pigs exhibited greater mature body weight than SC pigs (272.3 vs. 218.0 kg), with a later age at maximum growth rate ($p < 0.001$). Protein deposition was higher in IM pigs, which showed greater mature protein weight (39.2 vs. 30.9 kg) and delayed peak deposition compared with SC pigs ($p \leq 0.016$). Lipid deposition also differed between treatments, with IM pigs presenting greater mature lipid weight (93.9 vs. 72.0 kg) and a later age at maximum deposition ($p \leq 0.009$). Allometric analyses indicated faster protein deposition relative to body weight in IM pigs, whereas lipid accumulation increased more rapidly in SC pigs. In conclusion, immunocastration promoted greater growth potential, enhanced protein deposition, and delayed tissue maturity compared with surgical castration, indicating improved lean tissue accretion in male pigs.

Keywords: allometry; body composition; growth modeling; immunocastration; swine growth

Dinâmica de crescimento e particionamento de tecidos em suínos castrados cirurgicamente e imunocastrados: insights do modelo de Gompertz e análise alométrica

RESUMO: A imunocastração tem sido proposta como uma alternativa à castração cirúrgica devido aos seus efeitos no desempenho de crescimento e na composição da carcaça em suínos. Este estudo avaliou as curvas de crescimento e os padrões de deposição de tecido em suínos machos castrados cirurgicamente (SC) e imunocastrados (IM) utilizando os modelos de Gompertz e alométrico. Os parâmetros da curva de crescimento e a deposição de tecido foram estimados por meio de procedimentos de regressão não linear, e os coeficientes alométricos para deposição de proteína e lipídios em relação ao peso corporal foram avaliados. Os suínos IM apresentaram maior peso corporal adulto do que os suínos SC (272,3 vs. 218,0 kg), com idade mais tardia na taxa máxima de crescimento ($p < 0,001$). A deposição de proteína foi maior nos suínos IM, que apresentaram maior peso proteico adulto (39,2 vs. 30,9 kg) e pico de deposição tardio em comparação com os suínos SC ($p \leq 0,016$). A deposição de lipídios também diferiu entre os tratamentos, com os suínos IM apresentando maior peso de lipídios maduros (93,9 vs. 72,0 kg) e idade mais tardia para a deposição máxima ($p \leq 0,009$). As análises alométricas indicaram deposição de proteína mais rápida em relação ao peso corporal nos suínos IM, enquanto o acúmulo de lipídios aumentou mais rapidamente nos suínos SC. Em conclusão, a imunocastração promoveu maior potencial de crescimento, aumentou a deposição de proteína e retardou a maturação tecidual em comparação com a castração cirúrgica, indicando melhor acúmulo de tecido magro em suínos machos.

Palavras-chave: alometria; composição corporal; crescimento de suínos; imunocastração; modelagem de crescimento

* Henrique da Costa Mendes Muniz. E-mail: henriquemuniz@unipampa.edu.br. (Corresponding author)
Associate Editor: Lilian Francisco Arantes de Souza.

INTRODUCTION

Immunocastration is based on the administration of a vaccine containing a gonadotropin-releasing hormone (GnRH) analogue, which induces the production of antibodies against GnRH and consequently suppresses the hypothalamic–pituitary–gonadal axis (Dunchea et al., 2001; Zoels et al., 2020). This process reduces the synthesis of reproductive hormones and androgens, initially sensitizing the immune system after the first dose and effectively inhibiting gonadal function after the second dose (Dunshea et al., 2013). As a result, immunocastrated (IM) male pigs exhibit physiological and metabolic changes that markedly differ from those observed in surgically castrated (SC) animals, particularly during the finishing phase, affecting feed intake, growth rate, and body composition (van den Broeke et al., 2016; Muniz et al., 2019). These differences directly influence growth dynamics and tissue deposition patterns.

Animal growth can be described as a biological process driven by the deposition of body tissues and regulated by complex interactions among genetics, nutrition, environment, health status, hormonal profile, and sex (Henn et al., 2014; Wang et al., 2017). Characterizing growth curves allows for a better understanding of these processes, enabling the estimation of nutrient requirements, increasing production efficiency, reducing environmental impacts, and predicting the optimal age for slaughter (Pomar et al., 2009). In this context, modeling growth through mathematical functions provides a robust framework for describing not only overall body development but also the dynamics of tissue accretion.

In particular, the allometric relationship between protein and lipid deposition is a key aspect in understanding how animals partition nutrients during growth. Allometry describes the relative growth of body components and provides insight into biological priorities associated with energy utilization and tissue development (Henn et al., 2014; Carabús et al., 2017). This approach is especially relevant in modern pig production systems, where nutritional strategies are commonly defined based on body weight ranges (Carabús et al., 2017). Although such approaches are practical, they may not adequately account for differences related to sex, genotype, or physiological status, potentially limiting production efficiency and increasing nutrient excretion.

Despite the availability of studies describing growth curves in entire males, SC males, and females, information regarding the dynamics of tissue deposition in IM pigs remains limited, particularly concerning the quantitative relationship between protein and lipid accretion throughout growth. This lack of knowledge restricts the development of more precise nutritional and management strategies tailored to this category of animals.

Although previous studies (e.g., Muniz et al., 2019; Zoels et al., 2020; Pérez-Ciria et al., 2022) have evaluated the performance and nutritional requirements of IM pigs, integrated approaches combining growth curve modeling and allometric tissue deposition analysis are still lacking. This study advances current knowledge by linking Gompertz parameters with tissue partitioning dynamics, providing a more comprehensive biological interpretation of growth. We hypothesized that IM pigs would exhibit delayed physiological maturity, prolonged protein deposition, and altered protein-lipid partitioning dynamics compared with SC animals. Therefore, this study evaluated growth curve parameters and tissue deposition patterns, with emphasis on the allometric relationship between protein and lipid deposition in SC and IM male pigs.

MATERIALS AND METHODS

Animals and experimental design

In total, 48 male pigs of commercial genetics (Agroceres × Topigs) were used in this study, with an initial average body weight of 29.3 ± 1.9 kg at 75 days of age and a final average weight of 129.9 ± 9.0 kg at 177 days. Of these, 24 males underwent surgical castration on the third day of life, while the remaining 24 underwent immunocastration using Vivax® (Zoetis, Brazil), which contains 200 µg of anti-GnRH per milliliter in conjugated protein. IM pigs received two subcutaneous doses of 2 mL each at 121 and 149 days of age, with body weights of 81.3 ± 5.4 and 111.4 ± 7.5 kg, respectively.

The animals were housed in 24 pens with compact concrete floors, height-adjustable nipple drinkers, and semi-automatic feeders. The pigs were distributed among the pens according to weight and sex to ensure uniformity. All pigs received mashed feed *ad libitum* following a nutritional program divided into four phases. Diets were formulated to meet the nutritional requirements established by the National Research Council (2012), ensuring that the animals' nutrient demands were fully satisfied (Table 1). The pigs had free access to feed and water but were fasted for 12 hours prior to weighing.

Table 1 - Composition and calculated nutritional values of the diets

Ingredients	G-1	G-2	F-1	F-2
Corn	64.48	68.13	69.74	75.14
Soyabean meal (46% CP)	30.41	27.03	25.46	21.83
Soya oil	1.94	1.79	1.73	0.40
L-Lysine	0.32	0.31	0.29	0.27
DL-Methionine	0.14	0.11	0.13	0.07
L-Threonine	0.11	0.09	0.10	0.07
Limestone	0.74	0.77	0.78	0.76
Dicalcium phosphate	1.33	1.20	1.19	0.92
Salt	0.43	0.48	0.48	0.45
Mineral premix[1]	0.05	0.05	0.05	0.05
Vitamin premix[2]	0.05	0.05	0.05	0.05
Composition nutritional and energy				
Crude Protein, %	18.9	17.6	16.8	15.8
Metabolizable energy (ME), MJ.kg^{-1}	3300	3300	3300	3250
SID lysine (Lys), %	1.14	1.05	1.00	0.90
Lys: ME, (g.MJ^{-1})	3.46	3.17	3.03	2.76
Calcium, %	0.70	0.67	0.67	0.59
Standardized phosphorus, %	0.35	0.33	0.32	0.28
Sodium, %	0.17	0.19	0.19	0.18

G1– 24 days (30-50kg); G2– 28 days (50-80kg); F1– 25 days (80-105kg); F2– 26 days (105-130kg); 1Composition per kg of product: calcium: 98.800mg; cobalt: 185mg; copper: 15.750mg; iron: 26.250mg; iodine: 1.470mg; manganese: 41.850mg; zinc: 77.999mg; selenium: 105mg; 2 Composition per kg of product: folic acid: 116.55mg; pantothenic acid: 2.333mg; biotin: 5.28mg; niacin:5.600mg; pyridoxine: 175mg; riboflavin: 933.3mg; thiamine: 175mg; Vit. A: 1.225.000 U.I.; Vit. D3: 315.000 U.I.; Vit. E: 1.400mg; Vit. K3:700mg; Vit. B12: 6.825mg.

Growth Curve Modeling and Parameter Estimation

The animals were weighed twice weekly, and backfat thickness (BT) was measured every 2 weeks using ultrasonography. BT was used as a predictor of body composition based on the equations proposed by Cesaro et al. (2013). Lipid mass (LM) was estimated as LM = [(9.17 + 0.7 × BT) × BW ÷ 100], and protein mass (PM) was calculated as PM = (0.1277 × empty body weight − LM)$^{1.11}$. Empty body weight was estimated as 0.95 × BW. Ash and water contents were estimated as functions of PM, with ash = 0.2 × PM and water = 5.193 × PM$^{0.855}$.

For each animal, growth curve parameters and tissue deposition curves were estimated using the Gompertz equation (Equation 1) (Ferguson et al., 1994). Initial parameter values were defined based on biological criteria and literature values, and iterative procedures were applied to ensure model convergence. Nonlinear regression analyses were performed individually for each animal, allowing estimation of parameters A (mature weight), B (maturity rate), and C (age at maximum growth rate).

$$BW = A \times exp^{(-\exp(-B\times(age-C)))} \quad (1)$$

where "BW" is the pig's body weight, "A" indicates the weight at maturity, "B" is the maturity rate, and "C" is the age at which the maximum tissue deposition rate occurs (Nascimento et al., 2017). Using the parameters "A" and "B," the model proposed by Gous et al. (1999) was applied, with the result expressed in grams per day, representing weight gain at the respective age. The first derivative of the Gompertz function was used to describe the growth rate over time, allowing identification of the maximum growth rate and comparison between treatments.

To compare treatments, the equality of parameters and the identity of nonlinear models were evaluated according to the methodology proposed by Regazzi and Silva (2010), testing whether a single model could describe both treatments or whether separate models were required.

Allometric growth

Allometric relationships between tissue weight and body weight were described using Equation 2.

$$Y = a \times X^b \quad (2)$$

Where "Y" is the tissue weight, "X" is the pig body weight, "a" is the intercept of the logarithmic linear regression on "Y," and "b" is the growth coefficient, which describes the relationship between the related body constituents. If b = 1, Y grows at the same rate as X; if b > 1, Y grows proportionally faster than X; and the opposite is also true (Henn et al., 2014; Carabús et al., 2017). Allometric coefficients were interpreted in conjunction with Gompertz parameters to provide an integrated assessment of growth dynamics and tissue partitioning.

Statistical analysis

The parameters of the Gompertz growth model (A, B, and C) were estimated for each experimental unit using nonlinear regression procedures in RStudio (R Core Team, 2023). The models were fitted using the nlsLM() function from the *minpack.lm* package, based on the Levenberg–Marquardt iterative algorithm. Initial parameter values were defined from exploratory analyses to ensure model convergence. The estimated Gompertz parameters, as well as the allometric coefficients (a and b) related to protein and lipid deposition, were analyzed using linear models fitted with the lm() function. The statistical model adopted was Equation 3:

$$Y_{ij} = \mu + T_i + \varepsilon_{ij} \quad (3)$$

where Y_{ij} is the observed value of the parameter for the *j*-experimental unit under the i-treatment, μ is the overall mean, T_i is the fixed effect of the i-treatment, and ε_{ij} is the residual error.

Residual normality and homogeneity of variances were assessed using the Shapiro–Wilk and Levene tests, respectively. The identity of Gompertz curves between treatments was evaluated by comparing reduced and complete models using analysis of variance. Model adequacy was assessed based on lack-of-fit tests, the Akaike information criterion, the coefficient of determination (R^2), and graphical analysis of residuals. When treatment effects were significant ($p < 0.05$), means were compared using Tukey's test through the *emmeans* package

RESULTS

The growth curve parameters of SC and IM pigs differed significantly (Table 2; Figure 1). IM pigs exhibited a higher mature body weight (A = 272.3 kg) than SC pigs (A = 218 kg), although their maturity rate (B = 0.011) was slightly lower than that of SC pigs (B = 0.013). The age at maximum growth rate (C) was also delayed in IM pigs (145 days) relative to SC pigs (127.3 days), indicating that IM pigs grew for a longer period before reaching peak growth ($p < 0.001$ for all parameters) (Table 2).

Table 2 - Values for parameters in the Gompertz equation for castrated and immunocastrated male pigs, for growth parameters, protein and lipids deposits.

Traits	Growth parameters		
	A (kg)	B (day^{-1})	C (days)
CM	218	0.013	127
IM	272	0.011	145
RMSE	39	0.002	14
R^2	33.80%	21.30%	29.06%
P-value	<0.0001	0.0011	<0.0001
Traits	**Protein**		
	A (kg)	**B (day^{-1})**	**C (days)**
CM	31	0.014	117
IM	39	0.012	131
RMSE	7	0.002	16
R^2	27.20%	16.21%	16.33%
P-value	0.0002	0.0055	0.0059
Traits	**Lipids**		
	A (kg)	**B (day^{-1})**	**C (days)**
CM	72	0.011	169
IM	94	0.009	198
RMSE	27.43	0.002	28
R^2	14.33%	18.00%	21.16%
P-value	0.0087	0.0033	0.0011

Significant differences between means by Tukey's test ($p < 0.05$); RMSE: Root mean square error, R2: Coefficient of determination; A: weight at maturity, B: maturity rate, C: age at which maximum tissue deposition rate occurs

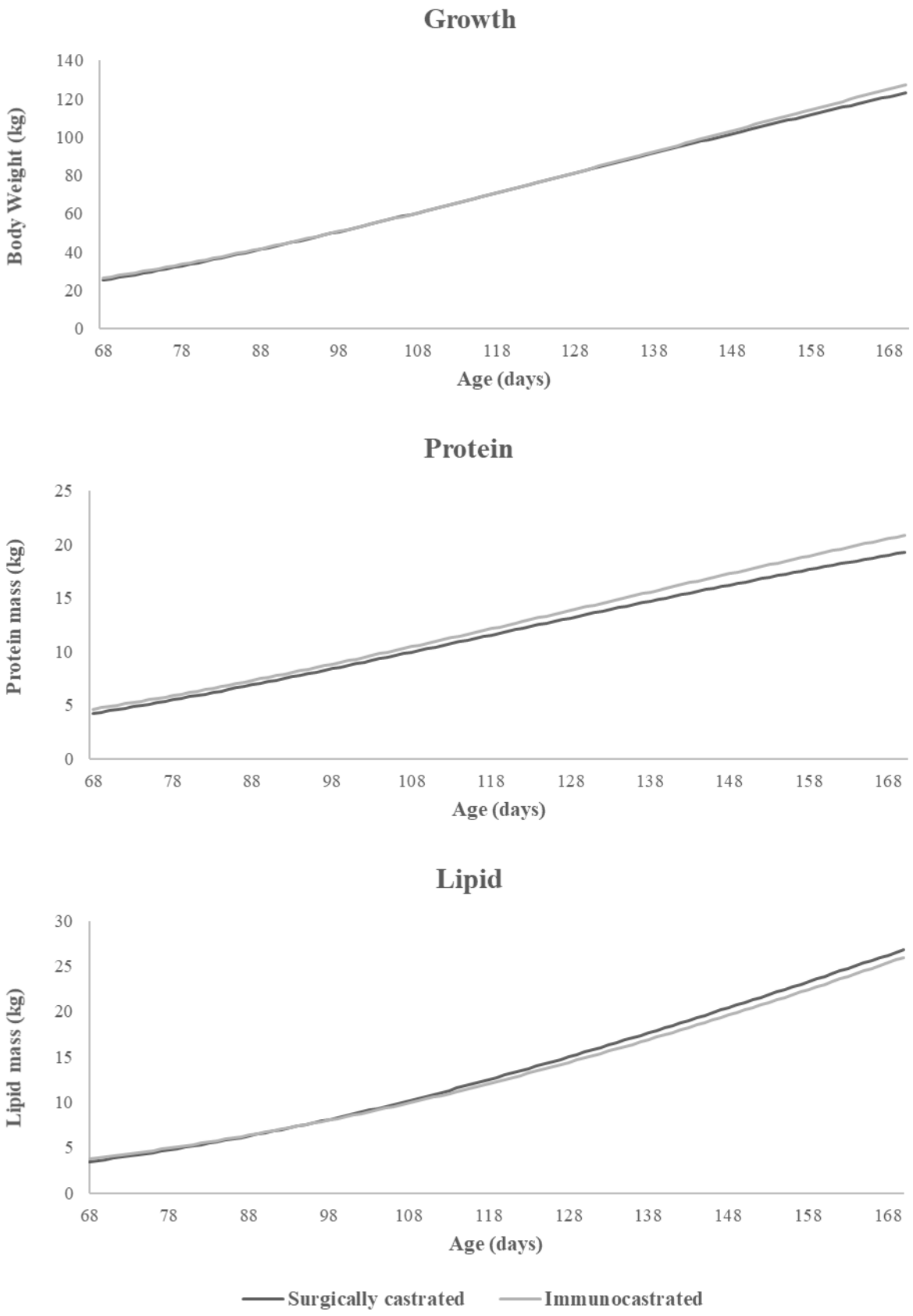

Figure 1 - Growth and tissue deposition in surgically castrated and immunocastrated male pigs.

Similar trends were observed for tissue deposition. Protein deposition in IM pigs reached a higher mature level (A = 39.2 kg) than in SC pigs (A = 30.9 kg), but the maturity rate was slightly slower (B = 0.012 vs. 0.014), and the age at maximum deposition was later (C = 134.1 vs. 117.1 days; $p \leq 0.016$). Lipid deposition showed an even greater difference, with IM pigs accumulating more fat at maturity (A = 93.9 kg) than SC pigs (A = 72 kg), but with a slower maturity rate (B = 0.009 vs. 0.011) and a later peak in deposition (C = 197.6 vs. 169.4 days; $p \leq 0.009$).

The allometric growth of protein and lipid tissues in relation to body weight differed between SC and IM male pigs (Table 3). For protein tissue, SC pigs had a slightly higher intercept (a = 0.214) but a lower allometric coefficient (b = 0.937) than IM pigs (a = 0.188, b = 0.972), indicating that protein deposition increased more rapidly with body weight in IM pigs ($p = 0.041$). By contrast, lipid tissue showed a higher intercept in IM pigs (a = 0.066) than in SC pigs (a = 0.058), but a lower allometric coefficient (b = 1.220 vs. 1.302), suggesting that lipid accumulation relative to body weight increased faster in SC pigs ($p = 0.023$). No significant difference was observed in the intercepts for either tissue type ($p > 0.05$), and mean square errors were relatively low, indicating a good fit of the allometric models.

Table 3 - Allometric growth of protein and lipid tissues in relation to body weight of castrated and immunocastrated male pigs

Sexual category	Parameters			
	Protein		Lipid	
	a*	b*	a*	b*
Castrated	0.214	0.937^{B}	0.058	1.302^{A}
Immunocastrated	0.188	0.972^{A}	0.066	1.220^{B}
MSE	0.007	0.008	0.005	0.018
p-value	0.061	0.041	0.386	0.023

MEP: Mean standard error; A-B: within the column indicates significant difference between means by Tukey's test ($P < 0.05$); * on top of the parameter means that its value differed from zero; a: intercept of the logarithm of linear regression; b: allometric growth coefficient.

Overall body weight increased steadily with age in both groups (Figure 1), with IM pigs showing slightly higher growth rates, particularly in the later stages. Protein deposition was consistently higher in IM pigs than in SC pigs throughout the observed period, reflecting a greater accumulation of lean tissue. Conversely, lipid deposition increased in both groups with age, but SC pigs exhibited slightly higher lipid accumulation than IM pigs, especially at older ages.

DISCUSSION

All pigs used in this study shared the same genetic background and were raised under identical nutritional and environmental conditions. Therefore, the differences observed in weight at maturity, maturity rate, and age at maximum tissue deposition for growth, protein deposition, and lipid deposition can be mainly attributed to sex category, in agreement with Ferguson & Kyriazakis (2003a). According to Ferguson & Kyriazakis (2003a), advances in genetic selection and production technologies are associated with increases in weight at maturity. In this context, the differences observed may be related to the use of immunocastration, which promotes greater growth potential and protein deposition.

Weight at maturity and maturity rate are key biological descriptors of the growth curve, as they reflect the degree of animal precocity (McManus et al., 2003). Weight at maturity is positively associated with the age at maximum tissue deposition and negatively associated with maturity rate. Thus, animals with a higher maturity rate tend to grow faster and reach physiological maturity earlier (Ferguson & Gous, 1993). Similar relationships have been reported in pigs of different sex categories (Carabús et al., 2017).

The age at which maximum tissue deposition occurs represents the point at which the animal reaches its highest growth rate (Gous et al., 1999). Beyond this stage, metabolic priorities shift because of changes in endocrine regulation, leading to a transition in the growth curve from an accelerating to a decelerating phase (Fialho, 1999; Neme et al., 2006). As a result, protein deposition gradually declines while lipid deposition increases, reducing growth efficiency (van Milgen & Noblet, 2003; Kloareg et al., 2006).

SC males exhibited earlier lipid deposition, reaching maximum fat accumulation before slaughter, unlike IM males. This earlier lipid deposition can be explained by the absence of gonadal hormones, which reduces protein accretion and promotes fat deposition (Schreurs et al., 2008). Consequently, carcass fat content increases, negatively affecting meat yield and potentially reducing consumer acceptance (Pauly et al., 2009; Muniz et al., 2021).

By contrast, IM males maintain anabolic hormonal activity for a longer period, supporting prolonged protein deposition and delaying fat accumulation. This interpretation is supported by findings showing that IM pigs present higher

concentrations of testosterone and estradiol than SC pigs prior to the second vaccination, depending on the vaccination schedule (Pérez-Ciria et al., 2022).

The variability observed in growth and protein deposition was higher than that reported by Ferguson & Kyriazakis (2003b). However, IM pigs showed lower variability than SC pigs. This difference may be related to the physiological constraints imposed by early surgical castration, which can affect the animals' ability to adapt uniformly to environmental conditions.

Lipid deposition showed high variability in both sex categories. According to Kyriazakis et al. (1994), lipid tissue is the most variable body component, which may partly explain this result. Ferguson & Kyriazakis (2003b) reported variability values of approximately 30%, similar to those observed in SC pigs. However, IM pigs showed even greater variability, which may be associated with individual differences in response to immunocastration. Because the effectiveness of the vaccine depends on the immune response, variability in hormonal suppression may influence the timing of lipid deposition. In agreement, Zoels et al. (2020) demonstrated that the response to GnRH vaccination and the resulting suppression of testicular steroids depend on the vaccination protocol, which can lead to differences in carcass traits and fat deposition among IM animals.

The allometric growth of protein in both sex categories was characterized by early development, consistent with the known sequence of tissue deposition: nervous, skeletal, muscular, and finally adipose tissue (Carabús et al., 2017). By contrast, lipid tissue exhibited later development, indicating increased fat accumulation toward the end of the fattening phase (Kloareg et al., 2006).

Lipid deposition occurred later than protein deposition in both SC and IM males, suggesting that pigs require diets rich in amino acids during the early stages of fattening to support efficient protein accretion. Notably, IM males reached their maximum growth rate approximately 18 days later than SC pigs. This delayed growth peak indicates a prolonged period of protein deposition and highlights the need for nutritional strategies adapted to their extended anabolic phase. In this context, Batorek et al. (2012) reported that IM pigs are physiologically similar to entire males before the second vaccination, which contributes to improved feed efficiency and sustained growth performance. These findings reinforce the importance of adjusting feeding programs to fully exploit the growth potential of IM pigs (Lewis, 2003; Henn et al., 2014; Muniz et al., 2019).

CONCLUSION

SC and IM pigs showed differences in growth curve parameters and tissue deposition patterns, confirming that the castration method influences growth dynamics. IM pigs exhibited changes in protein and lipid deposition consistent with hormonal modulation after immunization. The allometric analysis demonstrated that protein deposition occurs earlier, whereas lipid deposition increases at later growth stages in both groups. However, the rate and proportion of tissue deposition differed between SC and IM pigs. These results indicate that growth patterns and tissue deposition are affected by the castration method, highlighting the need for sex-specific nutritional strategies and optimized slaughter timing to improve production efficiency, carcass quality, and sustainability in pig production systems.

COMPLIANCE WITH ETHICAL STANDARDS

Authors' contributions: Conceptualization: HCMM; CSF; DDC; OT; RSV; MSS; Data curation: HCMM; OT; RSV; MSS; Formal analysis: HCMM; DDC; OT; Funding acquisition: HCMM; Investigation: HCMM; CSF; DDC; OT; RSV; MSS; Methodology: HCMM; DDC; Project administration: HCMM; Resources: HCMM; Software: HCMM; CSF; DDC; OT; RSV; MSS; Supervision: HCMM; Validation: HCMM; CSF; DDC; OT; RSV; MSS; Visualization: HCMM; CSF; DDC; OT; RSV; MSS; Writing – original draft: HCMM; OT; RSV; Writing – review & editing: HCMM; CSF; DDC; OT; RSV; MSS.

Conflict of interest: The authors declare no conflict of interest.

Funding: The Coordenacao de Aperfeicoamento de Pessoal de Nivel Superior - Brasil (CAPES) - Finance Code 001.

LITERATURE CITED

Batorek, N.; Čandek-Potokar, M.; Bonneau, M.; van Milgen, J. Meta-analysis of the effect of immunocastration on production performance, reproductive organs and boar taint compounds in pigs. Animal, v. 6, n. 8, p.1330-1338, 2012. https://doi.org/10.1017/S1751731112000146.

Carabús, A.; Sainz, R.D.; Oltjen, J.W.; Gispert, M.; Font-i-Furnols, M. Growth of total fat and lean and of primal cuts is affected by the sex type. Animal, v. 11, n. 8, p.1321-1329, 2022. https://doi.org/10.1017/S1751731117000039.

Cesaro, G.; Gallo, L.; Carraro, L.; Tagliapietra, F.; Bűnger, L.; Schiavon, S. Energy balance estimated from individual measurements of body weight and backfat thickness of heavy pigs of four genetic lines fed different diets. Agriculturae Conspectus Scientificus, v. 78, n. 3, p.221-224, 2013. https://acs.agr.hr/en/issues/article/708. 02 Aug. 2025.

Dunshea, F.R.; Allison, J.R.D.; Bertram, M.; Boler, D.D.; Brossard, L.; Campbell, R.; Crane, J.P.; Hennessy, D.P.; Huber, L.; de Lange, C.; Ferguson, N.; Matzat, P.; McKeith, F.; Moraes, P.J.U.; Mullan, B.P.; Noblet, J.; Quiniou, N.; Tokach, M. The effect of immunization against GnRF on nutrient requirements of male pigs: A review. Animal, v.

7, n. 11, p.1769-1778, 2013. https://doi.org/10.1017/S1751731113001407.

Dunshea, F.R.; Colantoni, C.; Howard, K.; McCauley, I.; Jackson, P.; Long, K.A.; Lopaticki, S.; Nugent, E.A.; Simons, J.A.; Walker, J.; Hennessy, D.P. Vaccination of boars with a GnRH vaccine (Improvac) eliminates boar taint and increases growth performance. Journal of Animal Science, v. 79, n. 10, p.2524-2535, 2001. https://doi.org/10.2527/2001.79102524x.

Ferguson, N.S.; Gous, R.M.; Emmans, G.C. Preferred components for the constrution of a new simulation model of growth, feed intake and nutrient requirements of growing pigs. South African Journal of Animal Science, v. 24, n. 1, p.10-17, 1994. https://journals.co.za/doi/10.10520/EJC-1ebd8a1d3b. 02 Aug. 2025.

Ferguson, N.S.; Gous, R.M. Evaluation of pig genotypes 1. Theoretical aspects of measuring genetic parameters. Animal Production, v. 56, n. 2, p.233-243, 1993. https://doi.org/10.1017/S0003356100021310.

Ferguson, N.S.; Kyriazis, S.T. Evaluation of the growth parameters of six commercial crossbred pig genotypes 1. Under commercial housing conditions in individual pens. South African Journal of Animal Science, v. 33, n. 1, p.11-20, 2003a. https://doi.org/10.4314/sajas.v33i1.3732.

Ferguson, N.S.; Kyriazis, S.T. Evaluation of the growth parameters of six commercial crossbred pig genotypes 2. Under ideal temperature conditions in chambers. South African Journal of Animal Science, v. 33, n. 1, p.21-26, 2023b. https://doi.org/10.4314/sajas.v33i1.3733.

Fialho, B. F. Interpretação da curva de crescimento Gompertz. Concórdia: Embrapa, 1999. 4p. (EMBRAPA-CNPSA. Comunicado Técnico, 237). http://www.infoteca.cnptia.embrapa.br/infoteca/handle/doc/437170. 28 Jul. 2025.

Gous, R.M.; Moran Jr, E.T.; Stilborn, H.R.; Bradford, G.D.; Emmans, G.C. Evaluation of the parameters needed to describe the overall growth, the chemical growth, and the growth of feathers and breast muscles of broilers. Poultry Science; v. 78, n. 6, p.812-821, 1999. https://doi.org/10.1093/ps/78.6.812.

Henn, J.D.; Bockor, L.; Ribeiro, A.M.L.; Coldebella, A.; Kessler, A. M. Growth and deposition of body components of intermediate and high performance broilers. Revista Brasileira de Ciência Avícola, v. 16, n. 3, p.319-328, 2014. https://doi.org/10.1590/1516-635x1603319-328.

Kloareg, M.; Noblet, J.; van Milgen, J. Estimation of whole body lipid mass in finishing pigs. Animal Science, v. 82, n. 2, p.241-251, 2006. https://doi.org/10.1079/ASC200529.

Kyriazakis, I.; Dotas, D.; Emmans G.C. The effect of breed on the relationship between feed composition and the efficiency of protein utilization in pigs. British Journal of Nutrition, v. 71, n. 6, p.849-859, 1994. https://doi.org/10.1079/BJN19940191.

Lewis, A. J. Amino acids in swine nutrition. In: Lewis, A. J.; Southern, L. L. (Eds.). Swine nutrition. 2.ed. Boca Raton: CRC, 2003. Chap. 8, p.131-149.

McManus, C.; Evangelista, C.; Fernandes, L.A.C.; Miranda, R. M.; Moreno-Bernal, F.E.; Santos, N. R. Curvas de crescimento de ovinos Bergamácia criados no distrito federal. Revista Brasileira de Zootecnia, v. 32, p.1207-1212, 2003. https://doi.org/10.1590/S1516-35982003000500022.

Muniz, H.C.M.; Lima, E.S.; Schneider, L.I.; Klein, D.R.; Rocha, L.T.; Nörnberg, J.L.; Quadros, A.R.B.; Oliveira, V. Carcass characteristics and meat quality of male pigs submitted to surgical or immunological castration. Anais da Academia Brasileira de Ciências, v. 93, n. 4; e20200130, 2021. https://doi.org/10.1590/0001-3765202120200130.

Muniz, H.C.M.; Rocha, L.T.; Kunzler, J.S.; Ceron, M.S.; Fraga, B.N.; Bottan, J.; Quadros, A.R.B.; Oliveira V. Evaluation of factorial methods to estimate lysine requirements for barrows and immunocastrated pigs. Livestock Science, v. 227, p.68-74, 2019. https://doi.org/10.1016/j.livsci.2019.07.003.

Nascimento, C.A.M.S.; Ribeiro, M.N.; Rocha, L.L.; Lucena; L.R.R. Avaliação de curvas de crescimento em suínos. Archivos de Zootecnia, v. 66, n. 255, p.317-323, 2017. https://doi.org/10.21071/az.v66i255.2506.

Neme, R.; Sakomura, N.K.; Fukayama, E.H.; Freitas, E.R.; Fialho, F.B.; Resende, K.T.; Fernandes, J.B.K. Curvas de crescimento e de deposição dos componentes corporais em aves de postura de diferentes linhagens. Revista Brasileira de Zootecnia, v. 35, p.1091-1100, 2006. https://doi.org/10.1590/S1516-35982006000400021

National Research Council – NRC. Nutrients requirements of swine. 11.ed. Washington: The National Academies Press, 2012. 400p.

Pauly, C.; Spring, P.; O'Doherty, J.V.; Ampuero Kragten, S.; Bee, G. Growth performance, carcass characteristics and meat quality of group-penned surgically castrated, immunocastrated (Improvac®) and entire male pigs and individually penned entire male pigs. Animal, v. 3, n. 7, p.1057-1066, 2009. https://doi.org/10.1017/S1751731109004418.

Pérez-Ciria, L.; Miana-Mena, F.J.; Álvarez-Rodríguez, J.; Latorre, M.A. Effect of castration type and diet on growth performance, serum sex hormones and metabolites, and carcass quality of heavy male pigs. Animals, v. 12, n. 8, e1004, 2022. https://doi.org/10.3390/ani12081004.

Pomar, C.; Hauschild, L.; Zhang, G.H.; Pomar, J.; Lovatto, P.A. Applying precision feeding techniques in growing-finishing pig operations. Revista Brasileira de Zootecnia, v. 38, n. spe., p.226-237, 2009. https://doi.org/10.1590/S1516-35982009001300023.

R Core Team. R: a language and environment for statistical computing. Vienna: R Foundation for Statistical

Computing, 2023. https://www.R-project.org/. 22 Jun. 2025.

Regazzi, A.J.; Silva, C.H.O. Testes para verificar a igualdade de parâmetros e a identidade de modelos de regressão não-linear em dados de experimento com delineamento em blocos casualizados. Revista Ceres, v. 57, n. 3, p.315-320, 2010. https://doi.org/10.1590/S0034-737X2010000300005.

Schreurs, N.M.; Garcia, F.; Jurie, C.; Agabriel, J.; Micol, D.; Bauchart, D.; Listrat, A.; Picard B. Meta-analysis of the effect of animal maturity on muscle characteristics in different muscles, breeds, and sexes of cattle. Journal of Animal Science, v. 86, n. 11, p.2872-2887, 2008. https://doi.org/10.2527/jas.2008-0882.

van den Broeke, A.; Leen, F.; Aluwé, M.; Ampe, B.; van Meensel, J.; Millet, S. The effect of GnRH vaccination on performance, carcass, and meat quality and hormonal regulation in boars, barrows, and gilts. Journal of Animal Science, v. 94, n. 7, p.2811–2820, 2016. https://doi.org/10.2527/jas.2015-0173

van Milgen, J.; Noblet, J. Partitiong of energy intake to heat, protein, and fat in growing pigs. Journal of Animal Science, v. 81, n. 14, suppl. 2, p.86-93, 2003. https://academic.oup.com/jas/article-abstract/81/14_suppl_2/E86/4789847. 02 Aug. 2025.

Wang, J.; Feng, C.; Liu, T.; Shi, M.; Wu, G.; Bazer F.W. Physiological alterations associated with intrauterine growth restriction in fetal pigs: Causes and insights for nutritional optimization. Molecular Reproduction & Development, v. 84, n. 9, p.897-904, 2017. https://doi.org/10.1002/mrd.22842.

Wellock, I.J.; Emmans, G.C.; Kyriazakis, I. Describing and predicting potential growth in the pig. Animal Science, v. 78, n. 3, p.379-388, 2004. https://doi.org/10.1017/S1357729800058781.

Zoels, S.; Reiter, S.; Ritzmann, M.; Weiß, C.; Numberger, J.; Schütz, A.; Lidner, P.; Stefanski, V.; Weiler, U. Influences of immunocastration on endocrine parameters, growth performance and carcass quality, as well as on boar taint and penile injuries. Animals, v. 10, n. 2, e346, 2020. https://doi.org/10.3390/ani10020346.