Veterinary and Animal Science 29 (2025) 100491

Contents lists available at ScienceDirect

Veterinary and Animal Science

journal homepage: www.elsevier.com/locate/vas

Productive performance and carcass quality of pigs from different sire lines under commercial production conditions

Julia Dezen Gomes [a], Bruna Pereira Martins da Silva [a], Stefano Francisco Pereira Duarte [a], Soraia Viana Ferreira [b], Vivian Vezzoni Almeida [c], Laura Woigt Pian [a], Fernanda Nery Ciconello [a], Cristina Tschorny Moncau Gadbem [d], Aline Silva Mello Cesar [*,a]

[a] *Luiz de Queiroz College of Agriculture, University of São Paulo, Avenue Pádua Dias 11, Piracicaba, São Paulo 13418-900, Brazil*
[b] *Danbred Brasil, Avenue Juscelino Kubitschek de Oliveira 2094, Patos de Minas, Minas Gerais 38706-000, Brazil*
[c] *Veterinary Medicine and Animal Science, Federal University of Goiás, Chácaras Califórnia, Goiânia, Goiás 74691-835, Brazil*
[d] *Department of Nutrition and Animal Production, School of Veterinary Medicine and Animal Science, University of São Paulo, Avenue Duque de Caxias Norte 225, Pirassununga, São Paulo 13635-900, Brazil*

ARTICLE INFO

Keywords:
Animal breeding
Immunocastration
Pigs efficiency
Pork

ABSTRACT

Crossbreeding between Duroc and Pietrain breeds is widely applied in genetic improvement programs to enhance productivity and carcass quality, aligning with sustainability goals and consumer demands. Additionally, sex is a relevant factor influencing performance and carcass traits. This study evaluate performance, carcass characteristics, and primary cut weights in pigs from different genetic lines and sexes, as well as their interactions. A total of 600 pigs were evaluated across three sire lines: Line D- Duroc, Line H- Hybrid (Duroc and Pietrain), and Line P- Pietrain, including both females and immunocastrated males (ICM). At the end of the growing period, 120 animals with body weights closest to the pen average were selected for slaughter and carcass analysis. No significant interactions were observed between genetic line and sex ($P \leq 0.05$). ICM showed superior average daily gain (ADG), final weight, feed conversion (FCR), and backfat thickness, while females had higher carcass yield and lean meat percentage. D and H lines outperformed P in carcass yield and weight, whereas P had greater backfat thickness but lower lean percentage and loin depth. For primary cuts, ICMs had heavier bellies, while females yielded more lean cuts. The results underscore the impact of genetic and sex-based selection on pork quality and sustainability.

Introduction

Pork is one of the most widely consumed meats worldwide and represents a major segment of global livestock production. In countries such as Brazil, the swine industry plays a critical economic and social role, contributing significantly to food security and rural development (Kim et al., 2024). The growing consumer demand for high-quality meat products has driven the industry to prioritize not only productivity but also carcass composition and meat quality attributes (Khanal et al., 2019; Lozada-Soto et al., 2022). As a result, breeding programs have increasingly focused on selecting animals with superior genetic potential for traits that align with market preferences (Mote & Rothschild, 2019).

In this context, genetic improvement refers to the process of selecting and breeding animals with desirable heritable traits to enhance productivity, product quality, and overall efficiency in livestock systems (Filho & Mourão, 2006a). When combined with strategic crossbreeding, it enables complementarity between lines and breed heterosis, enhancing genetic variability and optimizing traits such as feed conversion, weight gain, and meat quality (Lozada-Soto et al., 2022). Together, these strategies can improve traits such as feed efficiency, the ability of an animal to convert feed into body mass, thereby reducing production costs and environmental impact (Mote & Rothschild, 2019; Willson et al., 2020).

In turn, sustainability in swine production encompasses not only economic viability, but also the responsible use of resources and improvement of animal welfare (Mote & Rothschild, 2019). One key

* Corresponding author.
E-mail addresses: juliadezen@usp.br (J.D. Gomes), brunamartins@usp.br (B.P.M. da Silva), stefanoduarte@usp.br (S.F.P. Duarte), soraia@db.agr.br (S.V. Ferreira), vivian.almeida@ufg.br (V.V. Almeida), laura.woigt@usp.br (L.W. Pian), fernanda.ciconello@usp.br (F.N. Ciconello), alinecesar@usp.br (A.S.M. Cesar).

https://doi.org/10.1016/j.vas.2025.100491

Available online 30 July 2025

practice that contributes to this is immunocastration, a non-surgical method of suppressing reproductive function in male pigs using a vaccine against gonadotropin-releasing hormone (GnRH), which reduces aggressive behavior and boar taint while maintaining favorable growth performance (Mitjana et al., 2020; Poklukar et al., 2021). Furthermore, the preservation and integration of local pig breeds into production systems can also support sustainability by maintaining genetic diversity, promoting traditional high-quality meat products, and enabling extensive or outdoor farming systems that are increasingly valued by consumers (Razmaitė et al., 2024). Finally, carcass quality is often defined by characteristics such as lean meat yield, fat thickness, and the weight of primary cuts, which have direct implications for market value and consumer acceptance.

Among sire lines used in commercial systems, Duroc and Pietrain breeds are commonly employed due to their distinct and complementary characteristics (Soares et al., 2022). Duroc pigs are well known for their growth performance, robustness, and meat quality traits such as tenderness and intramuscular fat, making them ideal form improving feed conversion and carcass value (dos Santos et al., 2023; Soares et al., 2022). On the Other hand, Pietrain pigs are widely used to enhance lean meat yield and muscularity, as they tend to deposit less fat and produce carcasses with high lean content (Glinoubol et al., 2015; Sin Kim et al., 2020). Thus, the integration of genetic selection, strategic crossbreeding, and appropriate nutritional management contributes to the sustainable improvement of swine production, meeting the increasing demands of the consumer market (Soleimani et al., 2021).

In addition to genetic background, sex is another critical factor influencing growth performance and carcass composition (Daza et al., 2016; Lebret & Čandek-Potokar, 2022). Immunocastration has become a widely accepted alternative to surgical castration, improving animal welfare and maintaining desirable performance traits. ICM typically exhibit increased feed intake, greater subcutaneous fat deposition, and faster growth, particularly in the period following the second vaccine (Daza et al., 2016; Gispert et al., 2010). In contrast, female pigs often display a leaner carcass profile, with higher lean meat yield and carcass efficiency (Daza et al., 2016; Gispert et al., 2010; Lebret & Čandek-Potokar, 2022). These physiological differences are largely driven by hormonal factors, such as androgen levels, which influence energy metabolism and tissue deposition (Gispert et al., 2010; Škrlep et al., 2020).

Despite the widespread use of Duroc and Pietrain based sire lines and the relevance of sex-related variation in performance traits, relatively few studies have evaluated these factors under practical commercial conditions. Furthermore, the assessment of primary cut yields in addition to standard carcass traits remains limited, even though such parameters have direct economic relevance to the pork industry.

Therefore, the implementation of genetic improvement programs enables the maximization of pigs' productive potential by balancing rapid growth, feed efficiency, and carcass quality. Although sex cannot be predetermined at conception in current commercial swine systems, sex differences in performance should be considered in genetic selection and management strategies. Recognizing these differences allows for optimized feeding programs, slaughter timing, and genetic targets for each sex, supporting more efficient and sustainable production systems.

Thus, the objective of this study was to evaluate growth performance, carcass traits, and the weight of primary cuts in pigs from different paternal lines and sex categories.

Material and methods

The procedures involving the use of animals were approved by the Ethics Committee on Animal Use of the "Luiz de Queiroz" College of Agriculture (University of São Paulo, Piracicaba, Brazil, CEUA protocol number: 7416,051,222).

Pigs and experimental design

The experiment was on a commercial swine genetics farm, located in Varjão de Minas, Minas Gerais, Brazil, in the south-east of Brazil (842 m altitude, 18°34′ South latitude, and 46°31′ West longitude), a region with a tropical savanna with dry winter season (Aw) (Koppen, 1936 climate classification). The period encompassed the growing and finishing phases, lasting a total of 106 days. The facility featured natural ventilation and lighting, and pens with partially slatted concrete floors. Each pen equipped with a three-space automatic feeder and nipple drinkers, providing ad libitum access to mash feed and water throughout the trial.

The animals belonged to three genetic lines, which differed according to the sire used in each cross, while the same dam line (DanBred Hybrid, a cross between Yorkshire and Landrace) was used for all treatments. The paternal lines were considered the experimental treatments: Line D- Duroc; Line H- Hybrid (Duroc and Pietrain); and Line P-Pietrain. A total of 600 pigs were selected for the experiment, including 100 entire males and 100 females from each cross, with an average age of 63 days and an initial body weight (BW) of 20.27 ± 1.41 kg. The animals were allocated in pens of 25 animals, with each treatment group comprising four pens, totaling 24 pens in the experiment.

Entire males were immunocastrated by two 2 mL doses of Vivax (Zoetis, Parsippany, New Jersey, USA). The doses were administered at 105 days of age and 133 days of age, in accordance with manufacturer's recommendations.

The experiment was conducted using a completely randomized design, with of six treatments and four replicates per treatment. Animals were allocated in groups of 25 per pen (experimental unit), with four pens randomly assigned to each treatment, totaling 24 pens. Treatments were arranged in a 3 × 2 factorial design, with three genetic lines (D, H, and P) and two sexes (immunocastrated males – ICM and females).

The experimental diets, based on corn and soybean meal and supplemented with vitamins, minerals, and crystalline amino acids (L-lysine, DL-methionine, L-threonine, and L-tryptophan), were formulated according to the ideal protein concept. Nutritional requirements for the grower and finisher phases were established according to commercial recommendations for the genetic lines used in the study (Rostagno et al., 2011). The nutritional program was divided into six phases, according to the animals' body weight (BW), with adjustments to the nutritional levels in each phase. The grower phase diets were formulated to contain 1.10 % standardized ileal digestible (SID) lysine and 3.30 Mcal of metabolizable energy (ME)/kg, whereas the finisher phase diets contained 0.98 % SID lysine and 3.32Mcal ME/kg. Within each phase, all pigs fed the same diet.

Growth performance

Pigs were individually weighed at the beginning and end of the experimental period to determine average daily gain (ADG). Throughout the experimental period, feed supply and feed waste were recorded to determine the average daily feed intake (ADFI) per pen. Average (FCR) was calculated as the ratio between ADFI and ADG.

Slaughtering and carcass data collection

At the end of the experiment, when the pigs reached 169 days of age, five animals pen (n = 120; 20 pigs per treatment) were selected for slaughter (Fig. 1). Selection was based on body weight, and animals with body weights closest to the pen average were selected. This approach improves the reliability of treatment comparisons by reducing the influence of outliers.

All pigs were transported to a commercial slaughterhouse (Suinco, Patos de Minas, MG, Brazil), where pigs were subjected to electrical stunning followed by bleeding, in accordance with the slaughterhouse's standard procedures after 16-hour of lairage at the plant, without feed

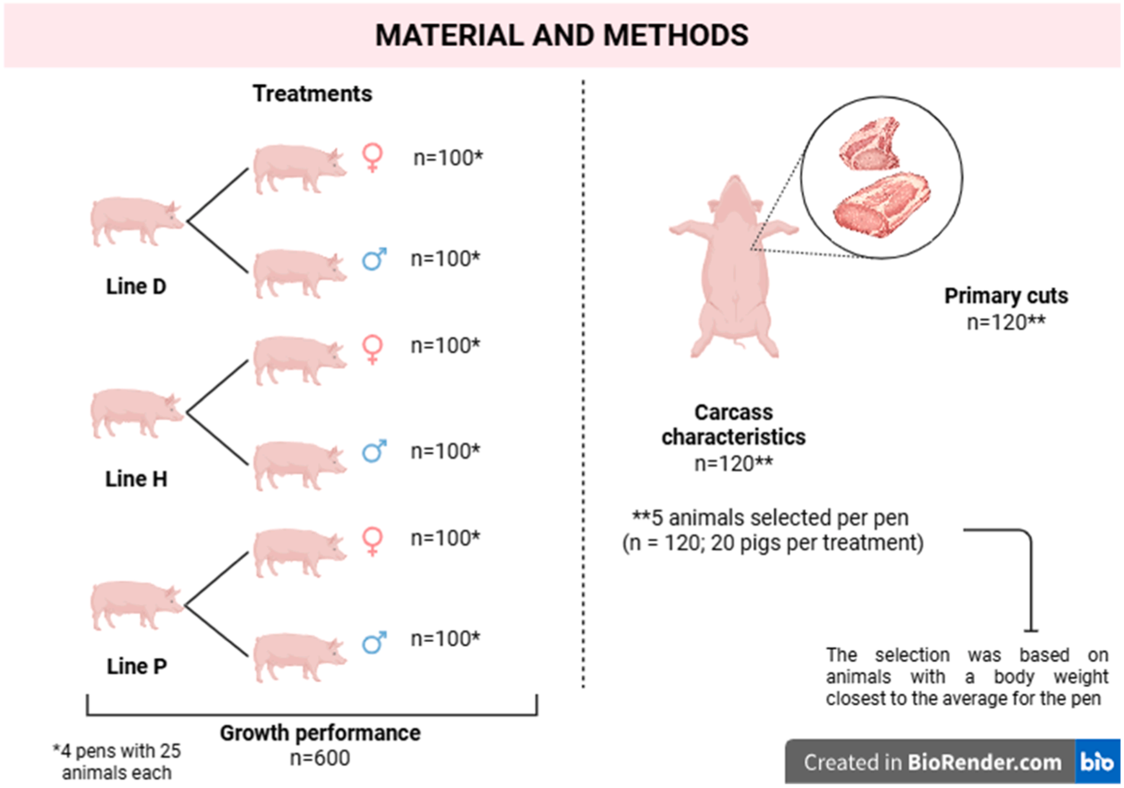

Fig. 1. Overview of the experimental design. Three sire lines (Duroc, Hybrid, and Pietrain) were evaluated, with each treatment comprising 100 entire males and 100 females, distributed into four pens of 25 pigs per sex. Five pigs per pen with body weights closest to the pen average were selected for carcass and primal cut analysis.

but with free access to water.

After bleeding, carcasses were subjected to scalding, dehairing, evisceration, longitudinal splitting, sanitary inspection, and were then promptly chilled in a cold chamber set at 4 °C for 24 h. The hot carcass weight, including jowl, was recorded immediately after slaughter. Carcass yield was calculated as the ratio between hot carcass weight to final live weight. Lean meat weight was determined from the combined weights of the bone-in ham, shoulder, and ribs, according to Caldara et al. (2013), whereas lean meat yield was estimated using the equation described by Groesbeck et al. (2007). After the 24-hour chilling period, the carcasses were reweighed to determine cold carcass weight. Backfat thickness and *Longissimus lumborum* (LL) muscle depth were measured between the 10th and 11th ribs on the left half of the carcass using a caliper.

Primary cuts

After 24 h of cooling, the carcasses were deboned by a trained professional in a commercial slaughterhouse. Cuts were made following technical specifications, ensuring standardization of the procedure (ABCS, 2010; Dalla Costa et al., 2020). The left half-carcasses were fabricated into different commercial cuts: shoulder, jowl, ham, rib, belly, tenderloin, picnic shoulder, and loin. Each cut was carefully removed, and the surrounding fat was separated according to the slaughterhouse's commercial standards. Subsequently, all commercial cuts were properly weighed.

Statistics analysis

Statistical analysis was performed using RStudio software (v.4.3.1). For the evaluation of growth performance, the pen was considered the experimental unit, whereas for carcass traits and primal cut weights, the individual pig served as the experimental unit. Prior to analysis, data were screened for outliers, and the assumption of normality was tested by applying the Shapiro–Wilk test to the residuals of each variable. Only data meeting the assumption of normality were included in the subsequent analyses. The statistical model included the fixed effects of genetic lineage, sex, and the interaction between genetic lineage and sex. There was no interaction between genetic lineage and sex; therefore, only the main effects were reported. For variables in which the effect of sex and/or genetic lineage was significant ($P \leq 0.05$), mean comparisons were conducted using Tukey's test at a 5 % significance level.

Results

Growth performance

Immunocastrated males showed an increased final BW ($P = 0.03$) and ADG ($P < 0.01$), as well as an improvement in FCR ($P < 0.01$), compared to females (Table 1). Concerning the evaluated lineages, pigs from D and H genetic lineage had a greater growth rate ($P = 0.02$) than those from P genetic lineage.

Carcass characteristics

Among the evaluated genetic lines, pigs from line D, with a terminal Duroc sire, exhibited a higher carcass yield ($P < 0.01$) compared to the other lines (Table 2). Statistical differences were observed among the genetic lines for the following carcass characteristics: hot carcass weight ($P = 0.03$), cold carcass weight ($P = 0.02$), lean meat content ($P < 0.01$), lean meat yield ($P < 0.01$), and loin depth ($P = 0.01$). For these traits, animals from lines D and H did not differ significantly, but pigs from line P had inferior results ($P < 0.05$). For hot carcass weight, pigs from line H exhibited higher values compared to pigs from line P ($P = 0.03$), whereas pigs from line D showed intermediate values, not differing significantly from either H or P. Additionally, pig from line P had the

Table 1
Effects of different genetic lineages and sexes on growth performance during the experimental period (106 days).

Item	Lineage[1]			Sex[2]		Pooled SEM[3]	*P*-value		
	D	H	P	ICM	F		Lineage	Sex	Lineage x Sex
BW[4] initial (kg)	20.58	20.32	19.90	20.37	20.16	1.41	0.89	0.86	0.57
BW[4] final (kg)	133.46	134.60	128.13	135.72	128.41	3.75	0.21	0.03	0.17
ADFI[4] (kg)	2.62	2.574	2.54	2.59	2.57	0.09	0.68	0.87	0.31
ADG[4] (kg)	1.07[a]	1.09[a]	1.03[b]	1.08	1.01	0.02	0.02	< 0.01	0.10
FCR[4]	2.43[b]	2.37[b]	2.53[a]	2.31	2.51	0.22	0.09	< 0.01	0.49

[1] Different sire lines: Line D- Duroc; Line H- Duroc and Pietrain; Line P- Pietrain.
[2] Sex category: ICM = Immunocastrated males; *F* = Females.
[3] Standard error of the mean.
[4] BW= Body weight; ADFI = Average daily feed intake; ADG = Average daily gain; FCR = Feed conversion ratio.
[a,b] Means within the same row followed by different letters differ significantly by genetic line or sex ($P \leq 0.05$).

Table 2
Evaluation of the effects of different paternal genetic lines (D, H and P) and sexes (ICM and females) on the carcass characteristics of pigs.

Item	Lineage[1]			Sex[2]		Pooled SEM[3]	*P*-Value		
	D	H	P	ICM	F		Lineage	Sex	Lineage x Sex
Hot carcass weight (kg)	97.99[ab]	98.45[a]	95.24[b]	96.97	97.55	1.27	0.03	0.60	0.12
Cold carcass weight (kg)	94.82[a]	94.92[a]	91.80[b]	93.15	94.53	1.23	0.02	0.20	0.37
Carcass yield (%)	73.49[a]	72.50[b]	71.90[b]	71.57	73.56	0.39	< 0.01	< 0.01	0.06
Backfat thickness (mm)	12.24[b]	13.24[b]	17.60[a]	15.57	13.16	0.92	< 0.01	< 0.01	0.90
Loin depth (mm)	82.39[a]	82.87[a]	79.00[b]	80.80	81.98	1.41	0.01	0.33	0.41
Lean meat (%)	61.14[a]	60.61[a]	57.74[b]	59.09	60.56	2.60	< 0.01	< 0.01	0.99
Lean meat (kg)	57.97[a]	57.35[a]	52.97[b]	55.03	57.18	0.86	< 0.01	< 0.01	0.46

[1] Different sire lines: Line D- Duroc; Line H- Duroc and Pietrain; Line P- Pietrain.
[2] Sex category: ICM = Immunocastrated males; *F* = Females.
[3] Standard error of the mean.
[a,b] Means followed by different letters in the same row, within genetic line or sex, differ significantly ($P \leq 0.05$).

highest backfat thickness ($P < 0.01$) compared to the other lines.

Regarding sex, females exhibited higher carcass yield ($P < 0.01$), lean meat content ($P < 0.01$), and lean meat yield ($P < 0.01$) compared to ICM. Conversely, ICM exhibited greater backfat thickness ($P < 0.01$) compared to females.

Primary cuts

Regarding sex, females had heavier ham ($P < 0.01$) and belly ($P = 0.01$) compared to ICM (Table 3). Conversely, ICM showed greater center rib roast ($P < 0.01$) weight compared to females. Concerning genetic lineage, pigs from the P lineage showed lower weights ($P < 0.01$) for ham, tenderloin and Boston butt, compared to lines D and H. For shoulder weight, pigs from lines D and P exhibited higher values compared to those from line H ($P = 0.04$). Regarding rib weight, pigs from line D showed the highest value, pigs from line P showed the lowest, and pigs from line H presented intermediate weights ($P < 0.01$). For Boston butt weight, pigs from line H exhibited higher value compared to pigs from lines D and P ($P < 0.01$).

Discussion

Genetic improvement and crossbreeding strategies are fundamental tools in modern swine production, especially in the pursuit of greater efficiency, meat quality, and sustainability (dos Santos et al., 2023). Among these strategies, the use of hybrid sire lines combining Duroc and Pietrain genetics has become increasingly common. Through mating and selection systems, the process operates on the principle that offspring tend to resemble their parents (Filho & Mourão, 2006b).

Line selection and crossbreeding aim to combine desirable traits, increasing productivity and aligning market demands shaped by consumer perceptions of meat quality (Filho & Mourão, 2006b; Miar et al., 2014; Srihi et al., 2024). However, the biological and productive consequences of such genetic combinations- particularly in relation to sex

Table 3
Evaluation of the effects of different paternal genetic lines (D, H and P) and sexes (ICM and female) on the primary cuts of pigs.

Item	Lineage[1]			Sex[2]		Pooled SEM[3]	*P*-Value		
	D	H	P	ICM	F		Lineage	Sex	Lineage x Sex
Shoulder (kg)	1.98[a]	1.85[b]	1.98[a]	1.94	1.94	0.06	0.04	0.97	0.61
Jowl (kg)	9.36	9.43	9.22	9.36	9.31	0.17	0.44	0.70	0.75
Ham (kg)	15.33[a]	15.04[a]	14.40[b]	14.58	15.26	0.26	< 0.01	< 0.01	0.43
Rib (kg)	3.59[a]	3.43[ab]	3.14[b]	3.41	3.37	0.13	< 0.01	0.68	0.74
Belly (kg)	5.88	5.83	6.11	5.75	6.11	0.18	0.24	0.01	0.59
Tenderloin (kg)	0.71[a]	0.76[a]	0.64[b]	0.70	0.70	0.02	< 0.01	0.79	0.13
Boston butt (kg)	2.29[b]	2.55[a]	2.27[b]	2.35	2.39	0.06	< 0.01	0.34	0.56
Center rib roast (kg)	8.66	8.75	8.41	8.78	8.44	0.18	0.17	0.02	0.06

[1] Different sire lines: Line D- Duroc; Line H- Duroc and Pietrain; Line P- Pietrain.
[2] Sex category: ICM = Immunocastrated males; *F* = Females.
[3] Standard error of the mean.
[a,b] Means followed by different letters in the same row, within genetic line or sex, differ significantly ($P \leq 0.05$).

and immunocastration- remain poorly characterized under commercial production conditions. These practices are important for the pig industry's sustainability and competitiveness, as they integrate both genetic and environmental factors to ensure consistent performance gains (dos Santos et al., 2023).

This study presents a comprehensive assessment of performance traits, carcass characteristics, and primal cut weights in pigs from distinct paternal lines, incorporating the effects of both genetic background and sex. By generating applied data under commercial production conditions, it addresses a critical knowledge gap and provides actionable insights to support genetic selection strategies and production planning.

The higher BW final and ADG observed in ICM is directly related to their superior feed conversion when compared to females. This indicates that ICM achieved greater weight gain per unit of feed intake, despite consuming similar feed amounts. This effect can be attributed to immunocastration, as pigs maintain similar physiological and performance characteristics to entire males until the second vaccine dose administration, including improved feed efficiency (Aluwé et al., 2016; Kress et al., 2019). Immunocastration substantially reduces androgen and estrogen, redirecting energy toward muscle mass development rather than reproductive activity or aggressive behaviors (Batorek et al., 2012). Consequently, ICM can convert feed more efficiently, resulting in greater final BW compared to females, without a proportional increase in feed intake.

Although genetic lineage showed limited effects on general performance, its influence on ADG was evident. Pigs from the line P demonstrated disadvantages in this growth variable, whereas lines D and H stood out for reaching the target weight in a shorter period of time. This contributes to improved productive efficiency and lower operational costs within the production system (Quan et al., 2018; Zhou et al., 2021). These results have a direct impact on the sustainability of swine production systems, as pigs with higher growth rates require less feed and water per unit of weight gained, thereby reducing the consumption of natural resources and minimizing waste generation.

In addition to performance, carcass quality is also a critical focus in pig production. Since the industry's modernization, improving carcass composition, particularly increasing lean meat relative to fat has been a key focus (Xia et al., 2023). Among the factors influencing these traits, genetic selection and the sex are considered strategies for improving carcass composition (Larzul, 2021; Zomeño et al., 2023).

Immunocastrated males pigs are traditionally associated with highter fat deposition compared to females, resulting in increased backfat thickness (Škrlep et al., 2020). In this study, ICM showed greater backfat thickness, confirming this difference. This effect may be directly related to immunocastration, as a notable increase in fat deposition typically occurs after the second vaccine dose due to reduce, in testosterone levels (Poklukar et al., 2021). However, there remains a lack of studies that thoroughly examine differences in backfat thickness between ICM and females, underlining the need for further research on their impact on carcass composition.

The results of this study showed that females had higher carcass weights and a greater proportion of lean meat compared to ICM, indicating a leaner body composition. This pattern was supported by the lower backfat thickness observed in females. These findings are consistent with previous studies reporting a higher lean meat percentage in female relative to ICM (Daza et al., 2016; Gispert et al., 2010). Moreover, females also showed higher carcass yield, highlighting significant sex-related differences in body composition.

These differences can be attributed to several physiological factors associated with immunocastration. Following the second vaccine dose, ICM experience suppression of gonadotropin- releasing hormone (GnRH), leading to testicular regression and cessation of testosterone production (Mitjana et al., 2020; Poklukar et al., 2021). This hormonal alteration enhances lipogenic activity and promotes fat deposition, particularly in visceral and subcutaneous region, thereby contributing to the lower lean meat content observed in ICM (Batorek et al., 2012; Poklukar et al., 2021).

Regarding genetic lines, this study identified notable advantages in carcass traits. As noted by Argemí-Armengol et al. (2019), carcass yield was one of the traits affected by genetic type. However, in this study, carcass yield was higher in pigs from the line D.

The Duroc breed, used as the paternal terminal line in this study, has been extensively subjected to genetic improvement programs over the past few decades, with a focus on growth efficiency, carcass yield, and higher lean meat percentage. As a result of this selective process, animals from this lineage tend to exhibit superior performance in traits associated with carcass composition, including greater muscle depth, lower fat thickness, and better utilization of primary cuts, compared to other genetic lines. These advances are supported by studies reporting moderate to high heritabilities for these traits in Duroc pigs, reinforcing the potential of this breed for use in selection programs aimed at carcass quality and productive efficiency (dos Santos et al., 2023; Willson et al., 2020).

Traditionally, the Pietrain breed is used as a sire to improve muscle mass and leanness, while the Duroc breed is generally associated with higher fat deposition (Argemí-Armengol et al., 2019; Edwards et al., 2006; Morales et al., 2013). However, the P line in this study underperformed in terms of carcass yield, lean meat content and yield, and loin depth. Additionally, the P line showed greater backfat thickness, contradicting the expected leaner profile reported by other authors (Morales et al., 2013). These results may be explained by the lower metabolic efficiency of these animals in the experiment, which may have led to less effective nutrient utilization, negatively affecting body composition. It is important to highlight that the entire experiment was conducted under standard commercial conditions, ensuring a controlled environment representative of current industrial production.

In contrast, pigs from the D and H lines excelled in carcass traits, particularly loin depth- a trait of high economic relevance in the pork industry due to its direct impact on the yield of valuable cuts (Desire et al., 2023). While D and H lines showed no significant differences in hot and cold carcass weights, line P pigs had notably; lower values. Similar findings were reported by Edwards, Bates and Osburn (2003), where Duroc-derived lines had heavier carcasses than Pietrain derived. Additionally, Glinoubol et al. (2015), in a comparison between Pietrain pigs and hybrids (Pietrain × Duroc), reported that hybrid pigs had higher cold carcass weights than pure Pietrain pigs, similar to the findings of this study. These differences in carcass weight influence the distribution and weight of commercial cuts, which is a key factor in determining value for the pork industry.

Thus, beyond carcass traits, commercial cuts also play an important role in the economic value of pigs. This study observed that both genetic lineage and sex influenced the weight of primary cuts, impacting the quality and economic value of the meat produced.

Animals from the D lineage, which showed the highest lean meat yield, also stood out for having the highest absolute weight of primary cuts~~, directly reflecting this trait~~. The greater lean meat yield in this lineage led to increased weights in high-value commercial cuts such as ham, rib, and tenderloin, compared to the other genetic lines. In contrast, pigs from the P lineage showed lower weights for these cuts, which is consistent with the carcass traits observed, as the P lineage had a lower percentage and yield of lean meat, thereby reducing the final weight of the cuts. These findings are in line with previous studies reporting that ham weight in pigs with Pietrain sires was lower than in those with Duroc or Duroc × Pietrain sires (Edwards et al., 2003; Glinoubol et al., 2015).

The H line, however, stood out for higher Boston butt weights compared to both D and P line, highlighting its superior performance in specific cuts. Its high lean meat yield was also associated with lower jowl weight, indicating reduced fat deposition in that area.

Similar to genetic lines, sex also significantly cuts. Immunocastred males pigs had lower ham weight and higher belly weights than females, reflecting to their lower lean yield and greater backfat thickness, findings that differ from some previous studies (Font-i-Furnols et al., 2023; Lowell et al., 2019). Interestingly, ICM pigs had heavier center rib roasts than females.

Thus, the results of this study contribute to a better understanding of the complexity behind primary cut weights, providing a foundation to optimize selection and management strategies in swine production systems in order to meet consumer preferences. Furthermore, the information obtained in this study can be used to promote more sustainable practices by identifying genetic lines that maximize productive performance and meat quality while also contributing to reduced consumption of natural resources such as feed and water, and lowering environmental impact through improved input efficiency.

Conclusion

This study demonstrated that sire line and sex significantly impact growth performance, carcass traits, and primary cut weights in pigs under commercial conditions. Females had higher carcass yield and lean meat content. In contrast, intact castrated males (ICM) exhibited superior growth and feed efficiency, though they had greater fat deposition. These findings enhance our understanding of genetic and physiological factors that influence carcass traits and can inform strategies for selection and management to meet industry and consumer demands. Furthermore, identifying genetic lines that enhance performance while minimizing resource consumption promotes more sustainable and efficient swine production. Future research should continue to refine genetic selection strategies that optimize productivity, meat quality, and environmental sustainability.

Declaration

All procedures involving animals followed the ethical standards outlined in the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching, and were approved by the Ethics Committee on Animal Use of the Luiz de Queiroz College of Agriculture, University of São Paulo (Piracicaba, Brazil), under number CEUA: 7416,051,222.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used ChatGPT in order to spelling corrections and contextual improvement. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the published article.

Funding

This work was supported by the São Paulo Research Foundation (FAPESP, grant number: 2023/02,067–7), and Brazilian National Council for Scientific and Technological Development (CNPq, grant number: 301,083/2018–5), which provided a researcher fellowship to A.S.M.C. This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior- Brasil (CAPES) - Finance Code 001.

Ethical statement

All procedures involving animals followed the ethical standards outlined in the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching, and were approved by the Ethics Committee on Animal Use of the Luiz de Queiroz College of Agriculture, University of São Paulo (Piracicaba, Brazil), under number CEUA: 7416,051,222.

CRediT authorship contribution statement

Julia Dezen Gomes: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Bruna Pereira Martins da Silva:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis. **Stefano Francisco Pereira Duarte:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis. **Soraia Viana Ferreira:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **Vivian Vezzoni Almeida:** Writing – review & editing, Writing – original draft, Methodology. **Laura Woigt Pian:** Writing – review & editing, Writing – original draft, Formal analysis. **Fernanda Nery Ciconello:** Writing – review & editing, Writing – original draft. **Cristina Tschorny Moncau Gadbem:** Writing – review & editing, Formal analysis. **Aline Silva Mello Cesar:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

We thank the collaborative efforts between the University of São Paulo, Danbred Genética Suína (Varjão de Minas, Minas Gerais, Brazil), Suinco slaughterhouse (Patos de Minas, Minas Gerais, Brazil) and Molecular Biology and Mycotoxins Laboratory.

References

ABCS, A. B.dos C.de S. (2010). *Manual brasileiro de suínos cortes*. https://agroceres multimix.com.br/Painel/uploads/11052016115405.pdf.

Aluwé, M., Degezelle, I., Depuydt, L., Fremaut, D., Van Den Broeke, A., & Millet, S. (2016). Immunocastrated male pigs: Effect of 4 v. 6 weeks time post second injection on performance, carcass quality and meat quality. *Animal : An International Journal of Animal Bioscience*, (9), 10. https://doi.org/10.1017/S1751731116000434

Argemí-Armengol, I., Villalba, D., Ripoll, G., & Álvarez-Rodríguez, J. (2019). Genetic but not lean grade impact on growth, carcass traits and pork quality under organic husbandry. *Livestock Science*, 227. https://doi.org/10.1016/j.livsci.2019.07.001

Batorek, N., Čandek-Potokar, M., Bonneau, M., & Van Milgen, J. (2012). Meta-analysis of the effect of immunocastration on production performance, reproductive organs and boar taint compounds in pigs. *Animal : An International Journal of Animal Bioscience*, (8), 6. https://doi.org/10.1017/S1751731112000146

Caldara, F. R., Moi, M., Dos Santos, L. S., De Lima Almeida Paz, I. C., Garcia, R. G., De Alencar Nääs, I., & Fernandes, A. R. M (2013). Carcass characteristics and qualitative attributes of pork from immunocastrated animals. *Asian-Australasian Journal of Animal Sciences, 26*(11). https://doi.org/10.5713/ajas.2013.13160

Dalla Costa, O. A., Tavernari, F.de C., Lopes, L.dos S., Dalla Costa, F. A., Feddern, V., & de Lima, G. J. M. M (2020). Performance, carcass and meat quality of pigs submitted to immunocastration and different feeding programs. *Research in Veterinary Science, 131*. https://doi.org/10.1016/j.rvsc.2020.04.015

Daza, A., Latorre, M. A., Olivares, A., & López Bote, C. J. (2016). The effects of male and female immunocastration on growth performances and carcass and meat quality of pigs intended for dry-cured ham production: A preliminary study. *Livestock Science, 190*. https://doi.org/10.1016/j.livsci.2016.05.014

Desire, S., Johnsson, M., Ros-Freixedes, R., Chen, C. Y., Holl, J. W., Herring, W. O., Gorjanc, G., Mellanby, R. J., Hickey, J. M., & Jungnickel, M. K. (2023). A genome-wide association study for loin depth and muscle pH in pigs from intensely selected purebred lines. *Genetics Selection Evolution, 55*(1). https://doi.org/10.1186/s12711-023-00815-0

dos Santos, J. C. R., Norenberg, A., Correia, B., Irgang, R., Bianchi, I., Moreira, F., de Oliveira Júnior, J. M., Nörnberg, J. L., & Peripolli, V. (2023). Evaluation of different percentages of Duroc genes and gender on growth, carcass and meat quality traits for pigs. *Meat Science*, 205. https://doi.org/10.1016/j.meatsci.2023.109314

Edwards, D. B., Bates, R. O., & Osburn, W. N. (2003). Evaluation of Duroc- vs. Pietrain-sired pigs for carcass and meat quality measures. *Journal of Animal Science, 81*(8). https://doi.org/10.2527/2003.8181895x

Edwards, D. B., Tempelman, R. J., & Bates, R. O. (2006). Evaluation of Duroc- vs. Pietrain-sired pigs for growth and composition. *Journal of Animal Science, 84*(2). https://doi.org/10.2527/2006.842266x

Filho, A. L., & Mourão, G. (2006a). *Melhoramento, raças e seus cruzamentos na pecuária de corte brasileira*. A. Filho (ed.); Vol. 1.

Filho, A. L., & Mourão, G. B. (2006b). *Melhoramento, raças e seus cruzamentos na pecuária de corte brasileira*. A. L. Filho (ed.).

Font-i-Furnols, M., Albano-Gaglio, M., Brun, A., Tejeda, J. F., Gispert, M., Marcos, B., & Zomeño, C. (2023). The effect of immunocastration of male and female Duroc pigs on the morphological, mechanical and compositional characteristics of pork belly. *Meat Science*, 204. https://doi.org/10.1016/j.meatsci.2023.109263

Gispert, M., Àngels Oliver, M., Velarde, A., Suarez, P., Pérez, J., & Font i Furnols, M. (2010). Carcass and meat quality characteristics of immunocastrated male, surgically castrated male, entire male and female pigs. *Meat Science, 85*(4). https://doi.org/10.1016/j.meatsci.2010.03.021

Glinoubol, J., Jaturasitha, S., Mahinchaib, P., Wicke, M., & Kreuzer, M. (2015). Effects of crossbreeding Thai native or Duroc pigs with Pietrain pigs on carcass and meat quality. *Agriculture and Agricultural Science Procedia, 5*. https://doi.org/10.1016/j.aaspro.2015.08.020

Groesbeck, C. N., Goodband, R. D., Tokach, M. D., Dritz, S. S., Nelssen, J. L., & DeRouchey, J. M. (2007). Effects of pantothenic acid on growth performance and carcass characteristics of growing-finishing pigs fed diets with or without ractopamine hydrochloride. *Journal of Animal Science, 85*(10), 2492–2497. https://doi.org/10.2527/JAS.2005-550

Khanal, P., Maltecca, C., Schwab, C., Gray, K., & Tiezzi, F. (2019). Genetic parameters of meat quality, carcass composition, and growth traits in commercial swine. *J. Anim. Sci, 97*, 3669–3683. https://doi.org/10.1093/jas/skz247

Kim, S. W., Gormley, A., Jang, K. B., & Duarte, M. E. (2024). Invited Review — Current status of global pig production: An overview and research trends. *Animal Bioscience, 37*(4). https://doi.org/10.5713/ab.23.0367

Kress, K., Millet, S., Labussière, É., Weiler, U., & Stefanski, V. (2019). Sustainability of pork production with immunocastration in Europe. *Sustainability, 11*(12). https://doi.org/10.3390/SU11123335

Larzul, C. (2021). How to improve meat quality and welfare in entire male pigs by genetics. *Animals, 11*(3). https://doi.org/10.3390/ani11030699

Lebret, B., & Čandek-Potokar, M. (2022). Review: Pork quality attributes from farm to fork. Part I. Carcass and fresh meat. *Animal : An international journal of animal bioscience, 16*. https://doi.org/10.1016/j.animal.2021.100402

Lowell, J. E., Schunke, E. D., Harsh, B. N., Bryan, E. E., Stahl, C. A., Dilger, A. C., & Boler, D. D. (2019). Growth performance, carcass characteristics, fresh belly quality, and commercial bacon slicing yields of growing-finishing pigs from sire lines intended for different industry applications. *Meat Science*, 154. https://doi.org/10.1016/j.meatsci.2019.04.010

Lozada-Soto, E. A., Lourenco, D., Maltecca, C., Fix, J., Schwab, C., Shull, C., & Tiezzi, F. (2022). Genotyping and phenotyping strategies for genetic improvement of meat quality and carcass composition in swine. *Genetics Selection Evolution, 54*(1). https://doi.org/10.1186/s12711-022-00736-4

Miar, Y., Plastow, G. S., Moore, S. S., Manafiazar, G., Charagu, P., Kemp, R. A., van Haandel, B., Huisman, A. E., Zhang, C. Y., Mckay, R. M., Bruce, H. L., & Wang, Z. (2014). Genetic and phenotypic parameters for carcass and meat quality traits in commercial crossbred pigs. *Journal of Animal Science*, (7), 92. https://doi.org/10.2527/jas.2014-7685

Mitjana, O., Bonastre, C., Tejedor, M. T., Garza, L., Latorre, M.Á., Moreno, B., & Falceto, M. V. (2020). Immuno-castration of female and male pigs with anti-gonadotrophin releasing hormone vaccine: Morphometric, histopathological and functional studies of the reproductive system. *Animal Reproduction Science*, 221. https://doi.org/10.1016/j.anireprosci.2020.106599

Morales, J. I., Serrano, M. P., Cámara, L., Berrocoso, J. D., López, J. P., & Mateos, G. G. (2013). Growth performance and carcass quality of immunocastrated and surgically castrated pigs from crossbreds from Duroc and Pietrain sires. *Journal of Animal Science*, (8), 91. https://doi.org/10.2527/jas.2012-6068

Mote, B. E., & Rothschild, M. F. (2019). Modern genetic and genomic improvement of the pig. *Animal agriculture: Sustainability, challenges and innovations*. https://doi.org/10.1016/B978-0-12-817052-6.00014-8

Poklukar, K., Čandek-Potokar, M., Vrecl, M., Batorek-Lukač, N., Fazarinc, G., Kress, K., Weiler, U., Stefanski, V., & Škrlep, M. (2021). The effect of immunocastration on adipose tissue deposition and composition in pigs. *Animal : An International Journal of Animal Bioscience*, (2), 15. https://doi.org/10.1016/j.animal.2020.100118

Quan, J., Ding, R., Wang, X., Yang, M., Yang, Y., Zheng, E., Gu, T., Cai, G., Wu, Z., Liu, D., & Yang, J. (2018). Genome-wide association study reveals genetic loci and candidate genes for average daily gain in Duroc pigs. *Asian-Australasian Journal of Animal Sciences, 31*(4). https://doi.org/10.5713/ajas.17.0356

Razmaitė, V., Šveistienė, R., & Šiukščius, A. (2024). Effects of genotype on pig carcass, meat quality and consumer sensory evaluation of loins and bellies. *Foods*, (5), 13. https://doi.org/10.3390/foods13050798

Rostagno, H. S., Albino, L. F., Donzele, J. L., Oliveira, R. F.de, Lopes, D. C., Ferreira, A. S., Barreto, S. L.de T.Euclides, R. F, … (2011). *Tabelas brasileiras para aves e suínos*. Viçosa: Universidade Federal de.

Sin Kim, Y., Kim, J., Dae Jeong, Y., Han Choi, Y., Seok Cho, E., Jae Chung, H., Jin Sa, S., Young Beak, S., & Ki Hong, J. (2020). Growth, body shape and carcass cutting yield traits of Duroc and Crossbred(Duroc×Pietrain×Pietrain)pigs. *Journal of the Korea Academia-Industrial Cooperation Society, 21*(7), 255–261. https://doi.org/10.5762/KAIS.2020.21.7.255

Škrlep, M., Tomašević, I., Mörlein, D., Novaković, S., Egea, M., Garrido, M. D., Linares, M. B., Peñaranda, I., Aluwé, M., & Font-I-furnols, M. (2020). The use of pork from entire male and immunocastrated pigs for meat products—An Overview with recommendations. *Animals, 10*(10). https://doi.org/10.3390/ani10101754. Issue.

Soares, M. H., de Amorim Rodrigues, G., Júnior, D. T. V., da Silva, C. B., Costa, T. C., de Souza Duarte, M., & Saraiva, A. (2022). Performance, carcass traits, pork quality and expression of genes related to intramuscular fat metabolism of two diverse genetic lines of pigs. *Foods*, (15), 11. https://doi.org/10.3390/foods11152280

Soleimani, T., Hermesch, S., & Gilbert, H. (2021). Economic and environmental assessments of combined genetics and nutrition optimization strategies to improve the efficiency of sustainable pork production. *Journal of Animal Science, 99*(3). https://doi.org/10.1093/jas/skab051

Srihi, H., López-Carbonell, D., Ibáñez-Escriche, N., Casellas, J., Hernández, P., Negro, S., & Varona, L. (2024). A multivariate gametic model for the analysis of purebred and crossbred data. An example between two populations of Iberian pigs. *Journal of Animal Breeding and Genetics, 141*(2). https://doi.org/10.1111/jbg.12832

Willson, H. E., de Oliveira, H. R., Schinckel, A. P., Grossi, D., & Brito, L. F. (2020). Estimation of genetic parameters for pork quality, novel carcass, primal-cut and growth traits in duroc pigs. *Animals*, (5), 10. https://doi.org/10.3390/ani10050779

Xia, J. Q., Liu, D. Y., Liu, J., Jiang, X. P., Wang, L., Yang, S., & Liu, D. (2023). Sex effects on carcass characteristics, meat quality traits and meat amino acid and fatty acid compositions in a novel Duroc line pig. *Journal of Animal Physiology and Animal Nutrition*, (1), 107. https://doi.org/10.1111/jpn.13680

Zhou, S., Ding, R., Meng, F., Wang, X., Zhuang, Z., Quan, J., Geng, Q., Wu, J., Zheng, E., Wu, Z., Yang, J., & Yang, J. (2021). A meta-analysis of genome-wide association studies for average daily gain and lean meat percentage in two Duroc pig populations. *BMC genomics, 22*(1). https://doi.org/10.1186/s12864-020-07288-1

Zomeño, C., Gispert, M., Čandek-Potokar, M., Mörlein, D., & Font-i-Furnols, M. (2023). A matter of body weight and sex type: Pig carcass chemical composition and pork quality. *Meat Science, 197*. https://doi.org/10.1016/j.meatsci.2022.109077