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Raising entire male pigs: comparison of growth performance and meat quality of the Bísara breed and a terminal cross - a pilot study

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Rearing entire male pigs presents several benefits, including enhanced feed efficiency, reduced environmental impact, and improved animal welfare. However, the risk of boar taint poses a significant challenge to pork quality. The objective of this pilot study is to evaluate growth performance, meat quality and the incidence of boar taint in intact male pigs of the Bísara breed (BI) and a terminal cross (TC). Five pigs from each breed were monitored during growth and blood samples were taken to measure tainting compounds (skatole and androstenone). The meat quality was compared concerning its colour, pH, and water-holding capacity (WHC). Bísaro pigs have more intensive muscle colour, higher WHC, and higher intramuscular fat content ($p<0.001$). No significant differences were noted for pH ($p>0.05$). TC pigs demonstrated more consistent growth patterns and faster growth during later stages. Meat quality analysis revealed statistically significant differences ($p < 0.05$) between the two groups in parameters such as thawing loss, moisture content, meat colour, and intramuscular fat, which favoured BI pigs. Conversely, TC pigs exhibited significantly lower levels of boar taint ($p<0.05$). The Bísara breed, which has not undergone intensive genetic selection, faces greater challenges in addressing boar taint compared to widely used commercial breeds. The emphasis on quantitative traits in BI breeding programs may have overshadowed the importance of qualitative traits. Therefore, exploring alternative and sustainable strategies to manage boar taint in Bísaro pigs is essential.

KEYWORDS

Bísara breed, Bísaro pigs, boar taint, crossbreeding, entire male pigs

1 Introduction

Raising entire male pigs eliminates the welfare concerns related to pain and stress caused by surgical castration (CA IPEMA, 2019). However, when raising intact males, avoiding the risk of boar taint is a notable challenge that both producers and the meat industry seek to minimise. Conversely, the absence of castration offers a significant animal welfare benefit provided taint can be prevented. The practice of castrating male piglets has been employed for generations to prevent the development of boar taint in the meat of some male pigs and remains widely used in most countries today (Bonneau and Weiler, 2019).

Also, this practice makes it easier to handle the pigs, as castrates have a lower probability of exhibiting agonistic behaviours and their sexual drive decreases as well (Font-i-Furnols et al., 2019). Boar taint is an unpleasant odour that can be present in the carcasses of entire male pigs (EFSA, 2004; Fredriksen et al., 2011; Wauters et al., 2017), typically found in the meat of 5 to 10% of uncastrated male pigs (Aluwé et al., 2020), mainly caused by the accumulation of two compounds: androstenone (AND) and skatole (SKA) (Duarte et al., 2021). These compounds accumulate in the adipose tissue as they reach puberty (Bonneau and Weiler, 2019), causing unpleasant odours and flavours that create negative perceptions of pork quality, among consumers.

Raising entire males eliminates castration costs and improves feed efficiency. Increased hormones during puberty can result in greater muscle growth, leading to higher lean meat content in the carcass (Bonneau and Weiler, 2019; Candek-Potokar et al., 2015). Despite its benefits, raising entire male pigs also presents some challenges, as this farming method can be more demanding for the farmer and more stressful for the animals (Candek-Potokar et al., 2015). Furthermore, managing more restless entire male pigs can be challenging for some farmers, as their agonistic behaviour and sexual drive can lead to injuries, particularly in the penis, legs, feet, and tail. These injuries can increase stress levels and decrease the immune function of the affected animals (Bonneau and Weiler, 2019; Squires et al., 2020). Meat quality of entire male pigs can also be affected, with characteristics such as increased toughness, reduced water holding capacity, lower intramuscular fat content, more frequent dark-firm-dry (DFD) meat, and increased protein oxidation (Bonneau and Weiler, 2019; Skrlep et al., 2019).

Pig growth performance represented by daily gain, feed conversion efficiency, and the content of lean meat has improved significantly by selection over the past decades and continues with the genetic and genomic technologies available (Mote and Rothschild, 2020). The Bísaro pig is a Portuguese native breed belonging to the Celtic line (*Sus celticus*). This breed is characterised by slow growth, suboptimal carcass conformation and medium fat and has always been recognised for its high prolificacy, exceptional sensory quality of the meat and aptitude for processing traditional meat products (Santos Silva et al., 2019).

The Large White breed, established in Yorkshire in the 1860s, is globally recognised. It has even influenced the development of the Landrace breed, created in Denmark by crossing Large White imports with local pigs (Amills et al., 2010; Bates, 2022). In the 20th century, breeds like Duroc and Pietrain became key in industrial crosses, but Yorkshire and Landrace have remained the foundation for many maternal lines. Crossbreeding in pigs is renowned for improving traits such as growth rate, feed efficiency, and reproductive performance through hybrid vigour (heterosis). Nonetheless, this emphasis has contributed to the decline of local breeds like Bísara. increasing interest has been shown in outdoor swine production systems due to the lower initial investment costs associated with facilities, buildings, and equipment (Araújo et al., 2016). At the same time, concerns with animal welfare and awareness of niche marketing opportunities have increased interest in free-range production (Albernaz-Gonçalves et al., 2021).

This pilot study aims to evaluate growth performance, meat quality, and the incidence of boar taint in intact males of the Bísara breed and a terminal cross of Piétrain × (Yorkshire × Landrace). The data collected serves also to assess the feasibility of developing a full trial and allow the determination of sampling efforts through power analysis.

2 Methods

2.1 Experimental design, husbandry and feeding

The study took place at the facilities of the Escola Superior Agrária of the Polytechnic Institute of Viana do Castelo (Portugal), in a hoop-barn system with outside access. A total of 10 entire male pigs – 5 Bísaro's and 5 terminal cross (TC) bred pigs (Piétrain x F1) – were separated into two groups. One Bísaro pig was separated from the test group at the end of the growth phase due to growth deficiencies of unknown cause. Bísaro pigs were obtained from pure breed producers. The terminal cross pigs were obtained in a commercial breeding unit, from crossing a synthetic hybrid maternal line of Large White x Landrace with a Pietrain paternal line. This results in a triple, terminal, and commercial cross for slaughter, also known as industrial cross.

The different genetic lines were separated and allocated into different pens. The indoor space was 7.5m^2 per Bísaro pig and 6.0 m^2 per terminal cross pig. Both groups had access to an outdoor area greater than 400 m^2 per pig. Both pens were equipped with nipple drinkers and bunker feeders. All animals present in this study were weighed every fortnight, using a Baxtran electronic scale (Giropès, Spain), whose weight limit is 150 kg and with an error of 50 g. The essay started with 48.0 ± 2.3 days of age and 12.9 ± 2.4 kg of live weight for the Bísaro's and 35.0 ± 0.0 days and 9.4 ± 0.8 kg for the terminal cross pigs. The pigs had a prior adaptation period of 14 days. The daily average housing temperature was 22.0 ± 1.3°C, and the relative humidity was 76.3 ± 4.5% during the experiment. The trial lasted 175 days for the Bísara breed and 168 days for the terminal cross pigs.

The feeding regimen was similar for both groups, and the feeds were administered *ad libitum* with a concentrate diet. Eventually, some additional feed was ingested through foraging outdoors. During the growth phase, which lasted 77 days for the Bísara breed and 70 days for the terminal cross, there was an average consumption of 1.0 kg of concentrate per pig per day. During the finishing phase, which lasted 98 days for both groups, the average feed consumption was 2.6 kg per pig per day. The chemical composition of the concentrate can be consulted in Table 1.

2.2 Pigs' growth evaluation

To evaluate the growth of the two pig genetic lines, the paired age (in days) and weight (in kg) were fit to the Gompertz growth model (Gompertz, 1825). The generic Gompertz equation assumes the form of Equation 1.

$$W(t) = a \cdot e^{\left(-b \cdot e^{(-ct)}\right)} \tag{1}$$

Where W(t) is the weight in kg at time t, and a, b and c are the parameters estimated. The Gompertz growth model has proved to fit pigs' growth very well and has been widely used by the scientific community (e.g. Ceron et al., 2020; Bo and Huong, 2023). After the calculation of the parameters of the models, the growth equations were obtained. The derivatives of the functions were also calculated to obtain the equations expressing the relative growth rate through time or growth velocity (kg/day). The equations were used to plot the growth and its velocity for both genetic lines.

2.3 Sampling

To perform the SKA and AND determination in the pig's plasma, individual blood samples from 9 pigs were collected when the Bísaro pigs' age was 181.0 ± 2.3 days and 91.3 ± 20.3 kg of weight, and terminal cross pigs were 147.0 ± 0.0 days old and 69.4 ± 8.7 kg. The blood was drawn from the marginal ear veins and collected in tubes with anticoagulant. Plasma was separated by centrifugation following the procedure by Wauters et al. (2015), collected into microtubes, and stored at -80°C. Extraction of compounds from plasma was carried out after thawing by adding 0.5 mL of 95% methanol to 0.5 mL of plasma, followed by centrifugation.

TABLE 1 Chemical composition of concentrate diets in the two phases (% m/m dry matter).

	Growing diet	Finishing diet
Moisture	12.85	13.14
Crude protein	16.20	13.66
Crude fat	3.15	2.70
Crude fibre	4.12	4.00
Lysine	1.02	0.89
Methionine	0.28	0.27
Ash	5.11	3.75
Calcium	0.95	0.50
Phosphorus	0.44	0.42
Sodium	0.13	0.17

After slaughter, both backfat and meat samples were obtained from each animal's neck area and *biceps femoris* respectively, and subsequently kept frozen at -18°C. Backfat samples were collected to extract liquid fat to determine boar taint concentration (SKA and AND), whereas meat samples from the central part of the ham (comprising *semimembranosus* and *biceps femoris*) were collected to determine the physicochemical characteristics of the meat. All samples were stored at −18°C for two weeks before further analysis. Analyte extraction for HPLC analysis consisted of extracting 1 g of liquid fat from adipose tissue after microwave heating and adding 1 ml of methanol. Samples were sonicated and centrifuged before passing through a 0.2 μm filter (Pereira-Pinto et al, 2024).

2.4 Skatole and androstenone quantification

SKA and AND from plasma and backfat samples were quantified using a simultaneous detection procedure based on Hansen-Moller (1994) and described by Pereira-Pinto et al. (2024). Briefly, manual derivatisation of samples was performed at room temperature for 5 min before injection with dansylhydrazine in 2-fold stoichiometric proportions. An external standard calibration method was applied, using various concentrations of standard solutions of SKA and AND. Chromatographic separation was achieved using acetic acid 0.1%, acetonitrile, tetrahydrofuran and methanol 95%. Fluorescence detection was performed with excitation at 285 nm, emission at 340 nm (0–6.0 min), followed by excitation at 346 nm and emission at 521 nm (6.1–13.0 min). The values of limit of detection (LoD) were 1.53 and 16.02 ng/g for SKA and AND, respectively. Analyte recovery values were 99.72 ± 2.34% for SKA and 102.84 ± 1.62% for AND.

2.5 Meat quality parameters

Intramuscular fat, thawing loss, moisture content, pH, colour (CIE L*a*b*) and total protein were determined in meat from *biceps femoris*. To determine the moisture content, samples were minced and dried in an oven at 103 ± 2°C until constant weight, as described in A.O.A.C (2016a). Colour measurements were performed according to the CIELAB colour system described by Honikel (1998). Meat sample colour was measured on a freshly cut surface using a Minolta CR-300 set (Konica Minolta, Tokyo, Japan) with D65 illuminant, recording L* a* b* values, where L* – lightness, a* – redness, and b* – yellowness. For thawing loss determination, samples were weighed, thawed at 4°C for 24 hours, dried with a paper towel and reweighed. Intramuscular fat (IMF) percentage was determined by a Soxhlet extraction procedure using petroleum ether as an extraction agent after sample hydrolysis, as described in the A.O.A.C. (2016b). For this analysis, the residual subcutaneous fat was removed during sample preparation using only lean muscle tissue. The pH was measured by potentiometry using the equipment Crison pH25+ (Crison Instruments, Barcelona, Spain), inserting the probe electrode into the meat samples. Crude protein in meat was determined following the A.O.A.C. (2016c).

2.6 Statistical analysis

Statistical analysis was performed using Statistica® for Windows software package, version 14.0.0.15 (TIBCO® Software, Palo Alto, California, USA). Data were tested for normality using the Kolmogorov-Smirnov test. Student's t-test was applied to test statistical differences between groups when normal distribution of the residuals was observed, as well as homogeneity of variances. When these assumptions were not verified, a non-parametric approach was used. The Mann-Whitney U-test was used to test the statistical difference between groups. Significant differences were established in $p<0.05$.

The Gompertz model parameters were estimated using the Levenberg–Marquardt algorithm. The curves were adjusted to the data using the NLR (Nonlinear Regression) routine of the SPSS® Statistics statistical package, version 28.0.1.1 (15) (IBM Corp.®, Armonk, NY, USA). The graphs were produced using Microsoft® Excel®.

3 Results

The results of animal live weight from the start of the experiment, as well as the growing and finishing phases, are summarised in Table 2. The average daily gain (ADG) increased for both genotypes between the initial growing phase and the finishing phase, rising from 0.452 kg/day (Bísara) and 0.398 kg/day (Cross) to 0.756 kg/day and 0.788 kg/day, respectively.

TABLE 2 Initial age and weight of pigs at the beginning, end of growing and end of finishing periods, average daily gain according to the genotypes (mean ± standard deviation).

	Bísaro	Terminal Cross
Beginning of the experiment		
Age (days)	48.0 ± 2.31	35.0 ± 0.00
Live weight (kg)	12.9 ± 2.41	9.4 ± 0.79
Growing phase		
Age (days)	125.0 ± 2.31	105.0 ± 0.00
Live weight (kg)	47.7 ± 4.52	37.2 ± 4.52
Average Daily Gain (kg)	0.452 ± 0.17	0.398 ± 0.05
Finishing phase		
Age (days)	223.0 ± 2.31	203.0 ± 0.00
Live weight (kg)	121.8 ± 24.00	114.4 ± 8.42
Average Daily Gain (kg)	0.756 ± 0.13	0.788 ± 0.07

The Gompertz models fitted out the data very well, with coefficients of determination very close to one. The parameters and the degree of adjustment of the models can be consulted in Table 3.

After replacement with the estimated parameters, Equations 2 and 3 respectively for the TC and Bísara genetic lines were obtained.

$$W(t)(TC) = 506.001 \cdot e^{\left(-4.848 \cdot e^{(-0.006t)}\right)} \tag{2}$$

$$W(t)(bísaro) = 326.580 \cdot e^{\left(-4.448 \cdot e^{(-0.007t)}\right)} \tag{3}$$

The Equations 4 and 5 are the first derivative of Equations 2 and 3 respectively,

$$\frac{dW(t)}{dt}(TC) = \frac{15888117 \cdot exp\left(\frac{556 \cdot \exp\left(\frac{7t}{1000}\right)}{2000} - \frac{7t}{1000}\right)}{1562500} \tag{4}$$

$$\frac{dW(t)}{dt}(bísaro) = \frac{459954909 \cdot exp\left(\frac{606 \cdot \exp\left(\frac{3t}{500}\right)}{125} - \frac{3t}{500}\right)}{31250000} \tag{5}$$

The plots of Equations 2 and 3 can be observed in Figure 1A, and the plots of Equations 4 and 5 can be observed in Figure 1B.

The results of the quality and colour parameters analysed in the meat are expressed in Table 4, showing significant differences (p<0.05) observed in terms of thawing-related moisture loss, moisture, and intramuscular fat content. Bísara's meat exhibited lower water loss following thawing (4.96% vs. 7.68%) and higher intramuscular fat content (3.78% vs. 2.42%). No significant differences were identified in pH levels, or total protein content. In terms of colour parameters, there were no discernible distinctions in the red component (a*). Nevertheless, it's noteworthy that the Bísara's meat displayed a darker shade (L*) compared to the TC (48.70 vs. 54.74, p<0.05) and exhibited a less pronounced yellowish hue (6.97 vs. 8.33, p<0.05).

The values for SKA and AND, which were determined in adipose tissue from the neck area, clearly show that the Bísara breed had significantly higher concentrations (p<0.05) in comparison to the TC (Table 5). Conversely, examinations conducted on plasma derived from *in vivo* blood sampling did not demonstrate significant differences between the breeds, mainly due to the great variability of results within the group, resulting in high standard deviations.

TABLE 3 Parameters of the Gompertz equation used to model the pigs' growth.

	Gompertz parameters coefficients			
Pigs' genetic line	a	b	c	R^2
Terminal Cross	506.001	4.848	0.006	0.999
Bísaro	326.580	4.448	0.007	0.994

The degree of fitness of the models was evaluated using the coefficient of determination (R^2).

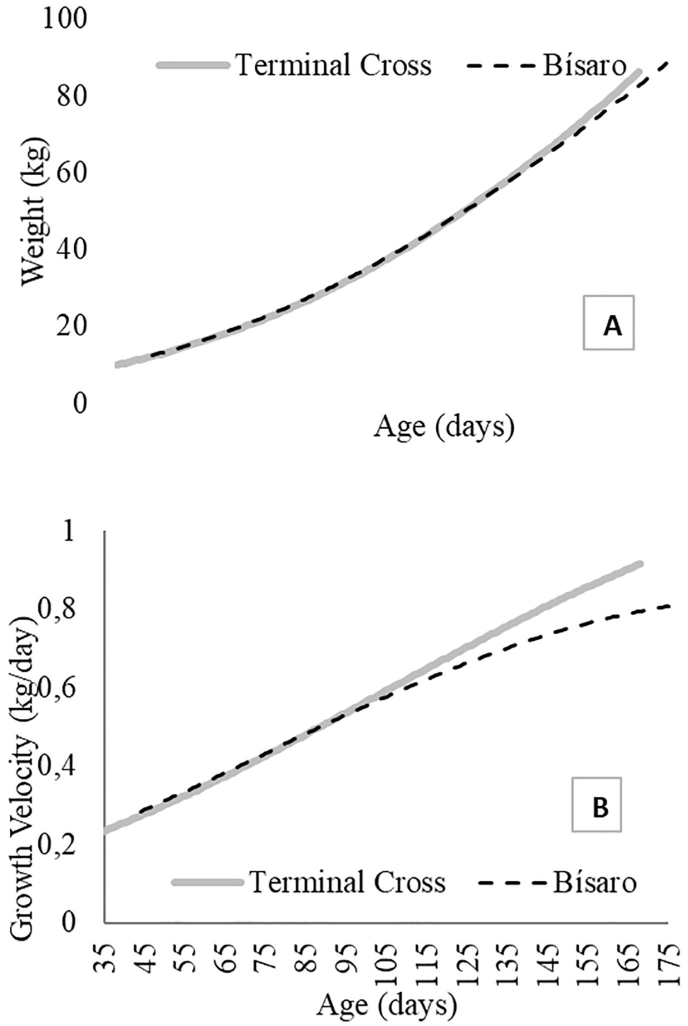

FIGURE 1
Gompertz model representing the growths of the two genetic lines of pigs indicated in the legend and used in the study **(A)**. Growth velocity or relative growth of the two genetic lines of pigs indicated in the legend and used in the study **(B)**.

4 Discussion

While comparing growth, it can be observed that the performance is very similar up to the age of approximately 120 days. From that point in time, the growth velocity of the genetic lines diverges, with the TC maintaining an increase in growth velocity, while in the Bísara breed, this tends to stabilise. Selection intensity has significantly influenced growth parameters across breeds, but it has also affected pork quality (Lebret, 2008; Miar et al., 2014; Willson et al., 2020). Local breeds such as the Bísara often exhibit superior organoleptic qualities due to more favourable fat distribution (Martins et al., 2020). This characteristic has been retained in these breeds, which have not undergone the intensive selection for lean meat typical of commercial breeds used in industrial crosses. Also, local breeds mature earlier in comparison to commercial breeds and their industrial crosses, which also justifies the higher concentrations of SKA and AND found in Bísaro pigs (Lebret and Čandek-Potokar, 2022).

TABLE 4 Meat quality and colour parameters determined in Bísara and Terminal Cross pigs.

	Breed		
	Bísaro	Terminal Cross	*p-value*
pH	5.44 ± 0.07	5.43 ± 0.05	0.62
Thawing loss (%)	4.96 ± 0.47	7.68 ± 1.28	<0.001
Intramuscular Fat (%)	3.78 ± 0.47	2.42 ± 0.22	<0.001
Protein (%)	24.89 ± 0.76	24.66 ± 0.86	0.44
Moisture (%)	73.45 ± 1.00	74.20 ± 0.54	0.02
L*	48.70 ± 3.65	54.74 ± 3.25	<0.001
a*	6.49 ± 0.93	6.42 ± 2.49	0.17
b*	6.97 ± 1.24	8.33 ± 2.05	0.03

TABLE 5 Boar taint compounds (skatole and androstenone) determined the pig's backfat and blood plasma.

Compound	Sampling Location	Breed		p-value
		Bísaro	Terminal Cross	
Skatole (ng/g)	Backfat	74.81 ± 38.17	8.69 ± 4.72	<0.001
	Blood plasma	5.09 ± 5.67	2.09 ± 0.54	0.31
Androstenone (ng/g)	Backfat	269.62 ± 159.94	137.60 ± 64.56	0.04
	Blood plasma	31.69 ± 40.72	67.18 ± 92.35	0.81

The Bísara breed demonstrated more desirable meat quality traits, including higher intramuscular fat content and lower water loss after thawing, although the TC meat had higher moisture content. This agrees with results obtained by other authors for the Bísaro breed pigs (e.g. Álvarez-Rodríguez and Teixeira, 2019; Paixão et al., 2018).

Regarding colour analysis, there are statistically significant differences in luminosity (L*) and yellow colour (b*), with Bísara meat being darker and less yellow. However, these colour differences are minimal and barely noticeable to untrained eyes. Variations in meat colour can be caused by many factors, including IMF content. The colour of pork is generally influenced by intramuscular fat (IMF), which is the fat embedded within lean meat by the muscle's connective tissue (Biswas and Mandal, 2022). Light scattering differences between pale and dark meat are mainly due to structural variations in muscle cells. Key factors include myofilament spacing, which affects fibre diameter, changes in sarcomere length, and variations in sarcoplasmic protein distribution (Purslow et al., 2020). There is also a strong correlation between water-holding capacity (WHC) and colour parameters. Greater WHC is typically associated with improved colour stability and reduced drip loss, helping to preserve the meat's visual appeal (Watanabe et al., 2018). In contrast to the findings of Martins et al. (2020), the pork samples in this trial exhibited significantly darker, redder, and yellower colour values. The lowest levels of L* observed in Bísaro pigs, are indicative of more intense colour of the meat, a distinctive feature appreciated by the consumer of Iberian breeds used in ham industry (Muriel et al., 2004). Moreover, pH can influence pork colour, with lower values leading to redder meat (Lindahl et al., 2006). However, in this study, no statistically significant differences in pH values were observed between the groups. Also, there were no statistically significant differences in protein content, or red colour (a*) between the TC and Bísara.

The observed concentrations of SKA and AND circulating in the bloodstream were generally low, with most values falling below the method's detection limit. The sensitivity of the equipment, and the presence of AND in its sulfonated form, may not be the sole factor for the low values found, as concentrations of AND and SKA in plasma can vary during the animal's lifetime (Bonneau et al., 1987; Zamaratskaia et al., 2004a, 2004b). Since these compounds accumulate in adipose tissue, fat analysis is the most suitable method for establishing a relationship between the concentrations found and the potential rejection of meat due to boar taint odour. Nevertheless, a notably high AND level in plasma was documented in one TC animal (224.16 ng/mL). It's worth noting that, in the analysis of backfat, this individual did not exhibit the highest AND values within the group. A significant limitation in this study is the age difference between the groups, which could influence the results due to variations in puberty progression. Furthermore, the different breeds involved have distinct puberty timings, making direct comparisons between the groups challenging. While boar taint can be diminished through selective breeding, involving performance testing (Squires et al., 2020, its prevalence varies among breeds, likely reflecting their distinct historical selection goals. Dam lines generally exhibit higher levels of boar taint than sire lines, likely due to their link with economically important traits. Selective breeding has shown the potential to reduce boar taint within a few generations (Mathur et al., 2013).

This study is declared as a pilot study and has a notable limitation related to the small sample size of the number of animals in the trial. This limitation may affect the generalisability of the findings, as a larger and more robust sample would allow a convenient statistical power. As further limitation there was a difference of 13 days of age when the piglets started the trial (48 days for the Bísaro, and 35 for the Terminal Cross) and a difference of seven days at the slaughtering age (175 days for Bísaro and 168 days TC). Future research should aim to include a significantly larger sample size to validate the present findings and ensure their relevance.

5 Conclusion

The growth performance of the terminal cross pigs was superior, however, the diminished growth performance in Bísara's may be compensated by the quality of the meat. Nonetheless, addressing the boar taint issue in Bísara´s, characterised by elevated levels of SKA and AND in the fat compared to the terminal cross, will require some effort. This issue might pose a significant challenge when it comes to raising intact male animals. Additional research employing a larger sample size of animals is necessary to validate these findings on a broader scale.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Ethics statement

This experiment was approved under Directive 2010/63/UE and Decreto-Lei 113/2013 by the Animal Welfare Committee (ORBEA) of Polytechnic Institute of Viana do Castelo, Portugal. (Reference DT1012-2024).

Author contributions

RP: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Resources, Visualization, Writing – original draft, Writing – review & editing. JA: Formal Analysis, Investigation, Methodology, Resources, Supervision, Validation, Writing – review & editing. JC: Resources, Validation, Writing – review & editing. FM: Formal Analysis, Investigation, Validation, Visualization, Writing – original draft, Writing – review & editing. PP: Validation, Writing – review & editing. MV: Funding acquisition, Project administration, Resources, Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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