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Age-Dependent Variations in Testicular and Epididymal Morphology of Mixed Nigerian Local–Exotic Boars

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ABSTRACT

Pigs are central to Nigeria's livestock sector, yet little is known about how age influences reproductive organ morphology in mixed local–exotic breeds. This study examined age related changes in testicular and epididymal morphology of mixed Nigerian local–exotic pigs using gross, morphometric, and histological methods. Testes and epididymides were collected from sixteen (16) non-descript boars at the Jos abattoir and commercial farms, and grouped into four categories ($n = 4$): prepubertal (1–4 months), pubertal (5–12 months), adult (13–24 months), and aged (>24 months). Testicular and epididymal gross bio-morphometric parameters (weight, length, width, and circumference), testicular histomorphometric indices [seminiferous epithelial height (SEH), seminiferous luminal diameter (SLD), and seminiferous tubular diameter (STD)], as well as epididymal histomorphometric indices [epididymal ductal epithelial height (EDEH), epididymal luminal diameter (EDLD), epididymal tubular diameter (EDTD), and periductal muscular thickness (EDPMT)] were assessed using standard procedures. Across groups, testes appeared large, creamy white, and ellipsoidal, while epididymides consistently showed a crescent shape with distinct divisions into caput, corpus, and cauda. Testiculo-epididymal weights were significantly reduced ($p < 0.05$) in aged pigs, whereas prepubertal pigs recorded lower values for most morphometric parameters. Overall, these measures increased progressively with age. Strong positive correlations were observed among biomorphometric parameters in both prepubertal and aged groups. Histology revealed mixed epithelial types in prepubertal epididymides, ranging from simple columnar to pseudostratified columnar, with no luminal spermatozoa. In contrast, pubertal, adult, and aged pigs exhibited typical pseudostratified columnar epithelium. Seminiferous and epididymal luminal and tubular diameters were significantly reduced ($p < 0.05$) in prepubertal pigs but increased steadily with age. This study provides essential baseline data on age-dependent testicular and epididymal morphology in mixed Nigerian local–exotic boars, linking structural changes to reproductive function and offering insights for breeding, veterinary practice, and sustainable pig production.

Keywords: Biomorphometry, Epididymis, Histology, Local-exotic Pigs, Testis

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Data Availability

Data supporting the findings are available from the corresponding author on reasonable request.

Introduction

The pig (*Sus scrofa domesticus*) is an important source of animal protein in Nigeria. It is a monogastric animal with a high rate of productivity and the ability to utilize a wide range of agro-industrial by-products and crop

residues with little or no processing and at minimal cost (Tewe and Adesehinwa, 1995; Igwe et al., 2013).

Nigeria is estimated to have 4.4 million pigs, with about 78% located in the sub-humid zones of the Northern and Southern Guinea savannah (Shaibu et al., 1997). Most

pigs are reared under extensive systems, where productivity has been reported to be low (Okorie, 1978). In some areas, uncontrolled interbreeding among pig breeds occurs (Foleng et al., 2014). The most common breeds used for commercial pig farming in Nigeria include Yorkshire, Landrace, Hampshire, Duroc, and their crosses (Agricdemy, 2019).

The paired mammalian testis is an oval structure situated in a specialized pouch of skin called the scrotum (Banks, 1993). It performs both exocrine (spermatozoa production) and endocrine (gonadal hormone secretion) functions (Monteiro et al., 2012). In most vertebrates, the testis is enveloped by a capsule (tunica vaginalis and tunica albuginea) whose architecture permits the entry and exit of blood vessels and nerves into the parenchyma (Aire and Ozegbe, 2007). The boar has large elliptical testes with thick tunics and adjacent epididymides, connected to the testis by efferent ducts and to the urethra by the ductus deferens (Sutovsky and Michael, 2018).

The epididymis is a single convoluted duct, also referred to as the ductus epididymis (Akbarsha et al., 2015). It connects the efferent ducts to the vas deferens (Singh, 2011), lies subjacent to the testis, and adheres to its medial side via connective tissue. Distally, it is secured by the ligament of the tail of the epididymis and the epididymal fat cushion (Dyce et al., 2002). The tail is dorsally oriented within the scrotum (Sutovsky, 2018). The boar epididymis is divided into three segments: caput (head), corpus (body), and cauda (tail) (Sutovsky and Michael, 2018).

Gross morphological studies of reproductive organs provide baseline information on parenchymal architecture, while morphometry estimates dimensions, tissue numbers, and ongoing activities (Gofur et al., 2015). Related investigations on boar testes and epididymis include spermiogram and morphological characteristics of testicular and epididymal spermatozoa in Large White boars in Nigeria (Oyeyemi and Ubiogoro, 2005); testicular development and the relationship between body weight, testis size, and sperm output in tropical boars (Ugwu and Foleng, 2009); growth of testes and testicular morphology after eight generations of selection for increased predicted testis weight at 150 days (Harder et al., 1995); and morphology of the testis and epididymis of Large White boars (Olukole and Oke, 2016).

There is limited information on age-related changes in the gross and histological features of the testes and epididymis of Nigerian local-exotic boars. This study therefore investigates age-related changes in testicular and epididymal morphology in mixed-breed boars in Jos, Nigeria. The hypothesis tested was that there are no significant age-related differences in the testicular and epididymal morphology of Nigerian local-exotic mixed-breed boars.

Materials and Methods

Sample Collection

Testes and epididymides were collected from sixteen apparently healthy, mixed-breed boars ranging in age from 2 to 48 months. The animals had record of been fed on standard commercial diets. Organ samples were obtained either at the Jos abattoir following slaughter or during routine castration procedures on reputable farms

within the Jos area. Estimated body weight (EBW) of each animal was obtained using a measuring tape prior to slaughter or castration. This was achieved by measuring body length (from the back of the head to the base of the tail) and girth circumference. Testicular and epididymal weights were measured using an analytical digital scale (Sartorius SE2, Model 4108).

To avoid the stress and handling required for conventional weighing, a validated weight estimation formula was applied. This method provided accurate body weight values from simple morphometric measurements, ensuring consistency while safeguarding animal welfare. The formula used was:

Estimated Hog weight (EHW) = $(HG^2 \times BL) / 400$ (Steichen et al., 2023). Where HG = Hog girth and BL = Body length

Experimental Design

Based on the age classification of boars reported by Czubaszek et al. (2020) (young: 6–12 months, adult: 18–24 months, older: ≥ 36 months), this study modified the grouping to better capture developmental stages. Boars were categorized into four groups: 1–4 months (prepubertal), 5–12 months (pubertal), 13–24 months (adult), and >24 months (aged).

Determination of Testicular and Epididymal Gross Bio-morphometric Parameters

The right and left epididymides were carefully excised from their respective testes. The weights of each testis and epididymis were measured using an analytical digital scale (Sartorius SE2, Model 4108). Relative organ weights: relative testicular weight (RTW) and relative epididymal weight (REW) were calculated using the formula:

Relative Organ's Weight (%) = $(\text{Weight of Organ (kg)} / \text{Weight of Animal (kg)}) \times 100$ (Zeder and Lemoine, 2022).

Gross biometric parameters, including right and left testicular lengths (RTL, LTL), epididymal lengths (REL, LEL), testicular widths (RTW, LTW), epididymal widths (REW, LEW), testicular circumferences (RTC, LTC), and epididymal circumferences (REC, LEC), were obtained following the description of Olukole et al. (2009). Length was defined as the distance between anterior and posterior borders, width as the distance between lateral and medial borders, and testicular circumference as the total distance measured around the mid-portion using a calibrated nylon tape.

Organ Excision and Histological Processing of Tissues

Abattoir samples of testis and epididymis were collected, nicked with a scalpel to permit smooth fixation, and placed in sample bottles containing 10% buffered formalin. Epididymal samples for histology were obtained from the caput (head), corpus (body), and cauda (tail) regions and fixed in separately labeled bottles. Formalin-fixed tissues were processed using routine histological techniques described by Omirinde et al. (2021).

Briefly, tissues were dehydrated in graded alcohol concentrations (70–100%), cleared in xylene, and embedded in paraffin wax. Wax blocks were sectioned at 5 μm thickness using a rotary microtome. Sections were

mounted on albuminized slides after floating on a warm water bath, dried in an oven, and stained with haematoxylin and eosin (H&E). Stained tissues were examined under a light microscope to assess histoarchitecture in relation to age.

Determination of Testicular and Epididymal Histomorphometric Parameters

Testicular histomorphometric parameters (seminiferous epithelial height [SEH], luminal diameter [SLD], tubular diameter [STD]) and epididymal parameters (epididymal ductal epithelial height [EDEH], luminal diameter [EDLD], tubular diameter [EDTD] and perimuscular coat thickness [EDPCT]) were determined using Motic software (Motic Images Plus 2.0 ML). A total of 40 round seminiferous tubules (10 per slide) and 20 epididymal ducts (5 per slide) from the caput, corpus, and cauda were evaluated from photomicrographs captured at $\times 100$ and $\times 40$ magnification, respectively. Histomorphometric measurements were performed using standardized protocols by the same observer throughout the study to ensure consistency. Although observer blinding was not implemented, uniform measurement criteria and procedures were applied across all samples to minimize potential observer bias.

The histomorphometric parameters were defined as follows:

1. **Seminiferous and epididymal epithelial heights (SEH, EDEH):** measured as the linear distance between the highest point of the epithelial lining and the basement membrane.
2. **Seminiferous and epididymal luminal diameters (SLD, EDLD):** obtained by placing four orthogonal lines across the luminal space.
3. **Seminiferous and epididymal tubular diameters (STD, EDTD):** determined using four orthogonal lines spanning the basement membrane with a common intersection.
4. **Epididymal periductal muscular thickness (EPMT):** measured as the linear distance from the external part of the coat to the basement membrane outline.

Statistical Analysis

Data were expressed as mean $\pm$ SE. One-way analysis of variance (ANOVA) was used to evaluate differences between groups, with $p < 0.05$ considered significant. Tukey's post hoc test was applied to assess group differences using GraphPad Prism 4.0 (GraphPad Software Inc., California, USA). Correlation and Principal Component Analyses (PCA) were conducted to establish relationships and identify the most informative parameters.

Results

Gross Appearance of the Testis and Epididymis of the Nigerian Mixed Breeds of Pigs

The paired testes were enclosed in the scrotal sac situated in the perineal region and directed backwards and upwards, approximately 6–8 cm below the anus. The testes were creamy-white in color, large, and regularly elliptical in shape. Across all age groups, they were grossly covered by a thick fibrous capsule, the tunica albuginea. The epididymis was firmly attached to the medial side of the testis via connective tissue and distally secured by the ligament of the tail of the epididymis and the epididymal fat cushion. The caput and cauda segments were firmly attached proximally and distally to the testis, respectively (Figure 1). Grossly, the right and left epididymides were less distinctly divided into caput, corpus, and cauda segments (Figure 2).

Gross Testicular and Epididymal Biomorphometric Parameters of the Nigerian Mixed Breed of Pigs

The results of age-related variation in testicular and epididymal biomorphometric parameters were presented in Table 1. Body weights (BW) of the pigs increased significantly ($p < 0.05$) with age. Extremes of BW (12.3 ± 5.14 g; 166.50 ± 6.63 g) were observed in prepubertal and aged pigs, respectively. Similarly, right and left testicular weights (RTW and LTW), paired testicular weight (PTW), right and left testicular length (RTL and LTL), and right and left testicular circumference (RTC and LTC) all increased significantly with age. Testiculo-somatic weight (TSW) was significantly reduced ($p < 0.05$) in aged pigs compared to other groups, while no significant differences ($p > 0.05$) were observed among prepubertal, pubertal, and adult pigs.

Epididymal parameters (REW: right epididymal weight; LEW: left epididymal weight; PEW: paired epididymal weight; REL: right epididymal length; LEL: left epididymal length) displayed a similar progressive increase from prepubertal to aged pigs. Epididymo-somatic weight (ESW) was markedly reduced in aged pigs, but no significant differences ($p > 0.05$) were observed among prepubertal, pubertal, and adult groups (Table 1).

The scatter plot matrix (Figure 3) of testicular biomorphometric parameters in prepubertal pigs showed strong positive correlations among BW, RTW, LTW, PTW, RTL, LTL, RTC, and LTC. The PCA (Principal Component Analysis) summary plot (Figure 3) revealed a component of 88%, indicating that these parameters were driven by the same genetic characteristics and had high predictive value. In pubertal pigs, the scatter plot matrix (Figure 3) showed varied correlations ranging from strong to weak, while RTC and LTC exhibited no correlation. The PCA summary plot (Figure 3) revealed a component of 45.7%, suggesting that parameters were less influenced by genetic traits and more by physical characteristics. In adult pigs, with the exception of RTC and LTC (which showed no correlation), other parameters exhibited varied positive correlations (Figure 4). The PCA summary plot (Figure 4) revealed a component of 45.7%, again reflecting a stronger influence of physical traits. In contrast, aged pigs displayed extremes of both strong negative and positive correlations across nearly all parameters (Figure 4). The PCA summary plot (Figure 4) revealed a component of

81%, indicating metrics largely driven by genetic characteristics with high predictive potential.

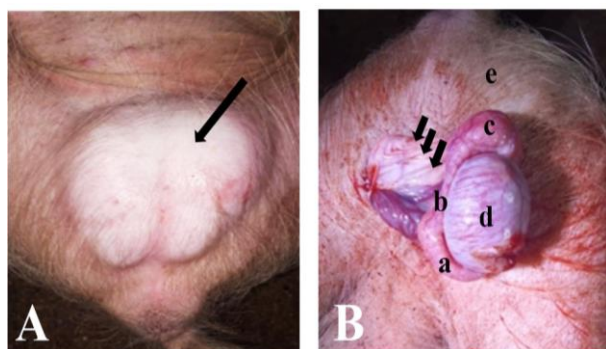


Figure 1. Photograph of the Scrotum (A)- ventral view and Male Gonads (Testis and Epididymis; Ex-situ B) of the Nigerian Mixed Breeds of Pigs. a – cauda (tail of epididymis), b – corpus (body of epididymis), c – caput (head of epididymis), d – testis, e – perineum, short arrows – tunica vaginalis- spermatic cord, long arrow – scrotum.

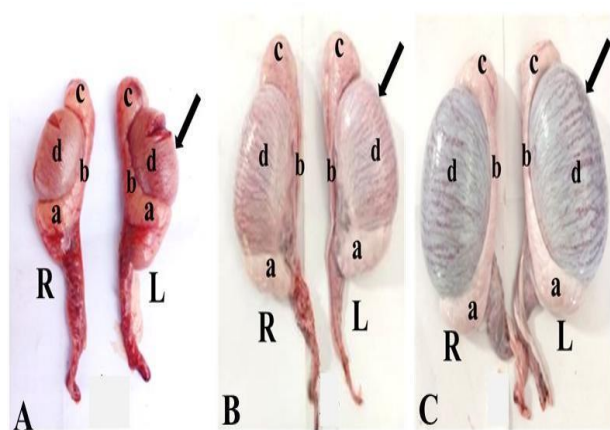


Figure 2. Photograph of the Testis and Epididymis of Prepubertal (A), Pubertal (B), and Adult (C) Nigerian mixed-breed pigs. R – Right male gonads, L – Left male gonads, a – caput (head of epididymis), b – corpus (body of epididymis), c – cauda (tail of epididymis), d – testis, arrow – testicular capsule

Age-related Changes in the Testicular and Epididymal Histology of the Nigerian Mixed Breed of Pig

The histological results of age-related changes in the testis and epididymis of local-exotic boars were presented in Figures 5-8. In prepubertal pigs, the testicular parenchyma was characterized by the progressive appearance of tiny lumina at the center of seminiferous tubules, with no evidence of luminal spermatozoa (Figure 5A). By contrast, pubertal and older pigs exhibited patent lumina and a complete germ cell series within the seminiferous tubules (Figure 5B-D).

The histological organization of the epididymis across age groups is shown in Figures 6-8. In prepubertal pigs, the caput epididymis displayed a mixture of epithelial cell types, ranging from simple columnar to pseudostratified columnar epithelium (Figure 6A). In pubertal, adult, and aged pigs, only the typical pseudostratified columnar epithelium was observed (Figure 6B-D). In the corpus epididymis, prepubertal pigs exhibited small, round lumina devoid of

spermatozoa (Figure 7A), whereas pigs in other age groups had larger lumina filled with abundant spermatozoa (Figure 7B-D). The cauda epididymal duct was consistently large and round across all age groups, but lacked spermatozoa in prepubertal pigs (Figure 8A). In pubertal to aged pigs, the cauda lumen was filled with numerous spermatozoa and lined by pseudostratified low columnar epithelium (Figure 8B-D).

Testicular and Epididymal Histomorphometry of the Nigerian Mixed Breed Pig

Testicular histomorphometric results were presented in Table 2. Seminiferous epithelial height (SEH) was significantly higher in adult pigs compared to other groups, showing a clear age-related increase. Seminiferous luminal diameter (SLD) was markedly reduced in prepubertal pigs. Apart from a significant decrease in adult pigs, SLD values generally increased with age. Seminiferous tubular diameter (STD) was significantly greater in adults relative to other groups, with a partial upward trend across age advancement.

Age-related differences in epididymal histomorphometry are shown in Figures 9-11A-D. Caput EDEH was significantly increased ($p < 0.05$) in adult and aged pigs compared to younger groups (Figure 9A), reflecting a progressive age-related trend. Caput EDLD and EDTD were significantly larger ($p < 0.05$) in pubertal pigs (Figure 9B-C), while caput EPMT was markedly greater in pubertal pigs compared to other groups (Figure 9D).

In the corpus epididymis, all four parameters, EDEH, EDLD, EDTD, and EPMT (Figures 10A -D), were significantly increased ($p < 0.05$) in aged pigs relative to other groups. In the cauda epididymis, EDEH was significantly reduced ($p < 0.05$) in prepubertal and aged pigs compared to others (Figure 11A). The EDLD and EDTD were significantly higher ($p < 0.05$) in adult pigs (Figure 11B-C), showing an initial increase with age followed by decline. The EPMT was significantly greater ($p < 0.05$) in adult pigs compared to other groups (Figure 11D).

Table 1. Age-Related Variations in the Testicular Bio-Morphometric Parameters in the Nigerian Mixed Breed of Pigs.

	TESTES			
	PRE-PUB	PUBERTAL	ADULT	AGED
EBW (kg)	12.33 ± 5.14 ^d	25.74 ± 5.14 ^c	49.68 ± 5.14 ^b	166.50 ± 6.63 ^a
RTW (g)	50.00 ± 20.00 ^c	110.00 ± 10.00 ^b	240.00 ± 20.00 ^a	280.00 ± 60.00 ^a
LTW (g)	60.00 ± 20.00 ^c	110.00 ± 0.00 ^b	220.00 ± 20.00 ^a	260.00 ± 30.00 ^a
PTW (g)	110.00 ± 40.00 ^b	210.00 ± 40.00 ^b	460.00 ± 40.00 ^a	540.00 ± 50.00 ^a
TSW (%)	0.81 ± 0.19 ^a	0.84 ± 0.04 ^a	0.93 ± 0.07 ^a	0.34 ± 0.05 ^b
RTL (cm)	9.32 ± 0.76 ^c	11.98 ± 0.76 ^b	12.94 ± 0.76 ^b	16.00 ± 0.98 ^a
LTL (cm)	9.92 ± 0.72 ^b	11.66 ± 0.72 ^b	12.38 ± 0.72 ^b	15.93 ± 0.92 ^a
RTC (cm)	14.98 ± 1.25 ^c	20.44 ± 1.25 ^b	23.75 ± 1.25 ^{ab}	27.99 ± 1.62 ^a
LTC (cm)	15.42 ± 1.42 ^c	21.02 ± 1.42 ^b	24.53 ± 1.42 ^{ab}	28.32 ± 1.83 ^a
	EPIDIDYMIS			
	PRE-PUB	PUBERTAL	ADULT	AGED
REW (g)	27.00 ± 10.00 ^c	50.00 ± 10.00 ^b	80.00 ± 10.00 ^{ab}	100.00 ± 10.00 ^a
LEW (g)	10.00 ± 0.00 ^c	50.00 ± 0.00 ^{bc}	70.00 ± 10.00 ^b	110.00 ± 10.00 ^a
PEW (g)	50.00 ± 15.00 ^d	100.00 ± 15.00 ^c	140.00 ± 15.00 ^b	215.00 ± 19.00 ^a
ESW (g)	0.40 ± 0.07 ^a	0.40 ± 0.05 ^a	0.28 ± 0.02 ^a	0.14 ± 0.02 ^b
REL (cm)	13.76 ± 1.02 ^c	20.68 ± 1.02 ^b	24.36 ± 1.02 ^{ab}	28.43 ± 1.32 ^a
LEL (cm)	13.30 ± 1.37 ^b	20.94 ± 1.37 ^a	23.96 ± 1.37 ^a	27.17 ± 1.76 ^a

Values in the different alphabet (a, b, c, d) superscripts are significantly different. BW - Body Weight, TSW – Testiculo-somatic weight, RTW – Right Testicular Weight, LTW – Left Testicular Weight, PTW – Paired Testicular Weight, RTL – Right Testicular Length, LTL – Left Testicular Length, RTC – Right Testicular Circumference, LTC – Left Testicular Circumference, ESW – Epididymo-somatic weight, REW – Right Epididymal Weight, LEW – Left Epididymal Weight, PEW – Paired Epididymal Weight, REL – Right Epididymal Length, LEL – Left Epididymal Length

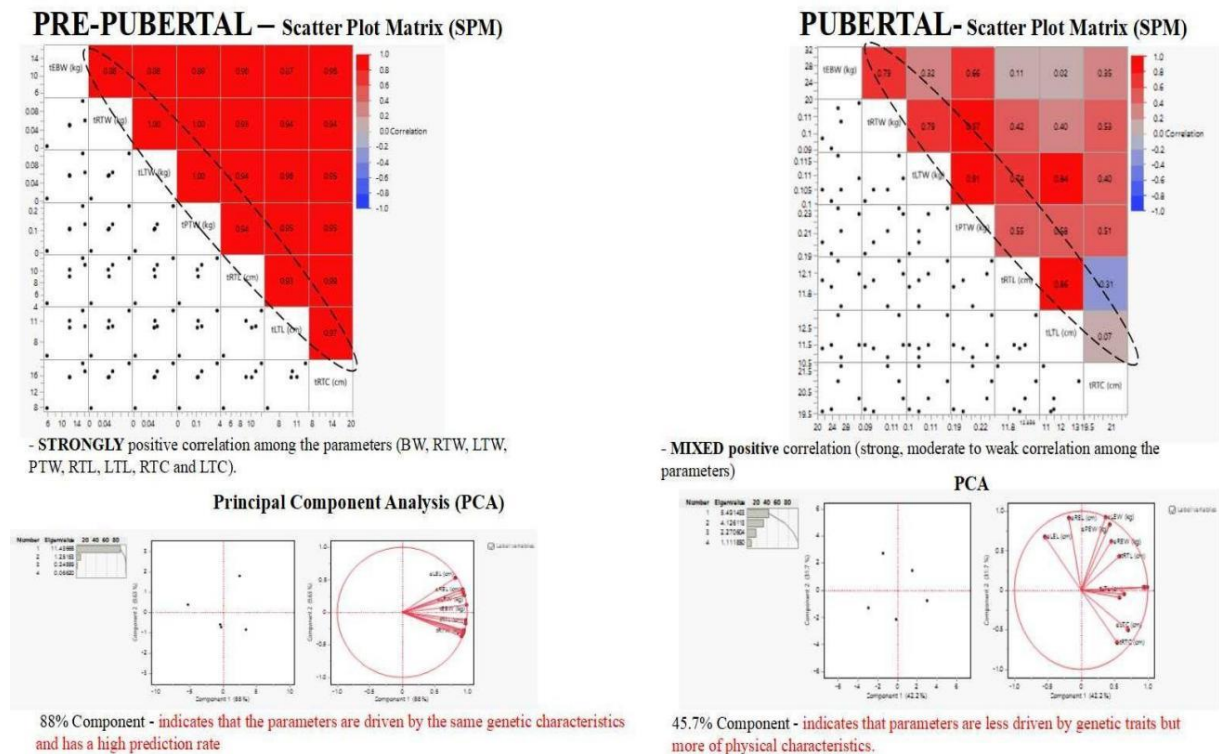


Figure 3. Scatter plot matrices and Principal Component Analyses of pre-pubertal and pubertal correlative analysis of testicular biomorphometric parameters of different age groups of boars. Note: strongly positive and mixed correlation respectively exist among testicular biomorphometric parameters in pre-pubertal and pubertal boars.

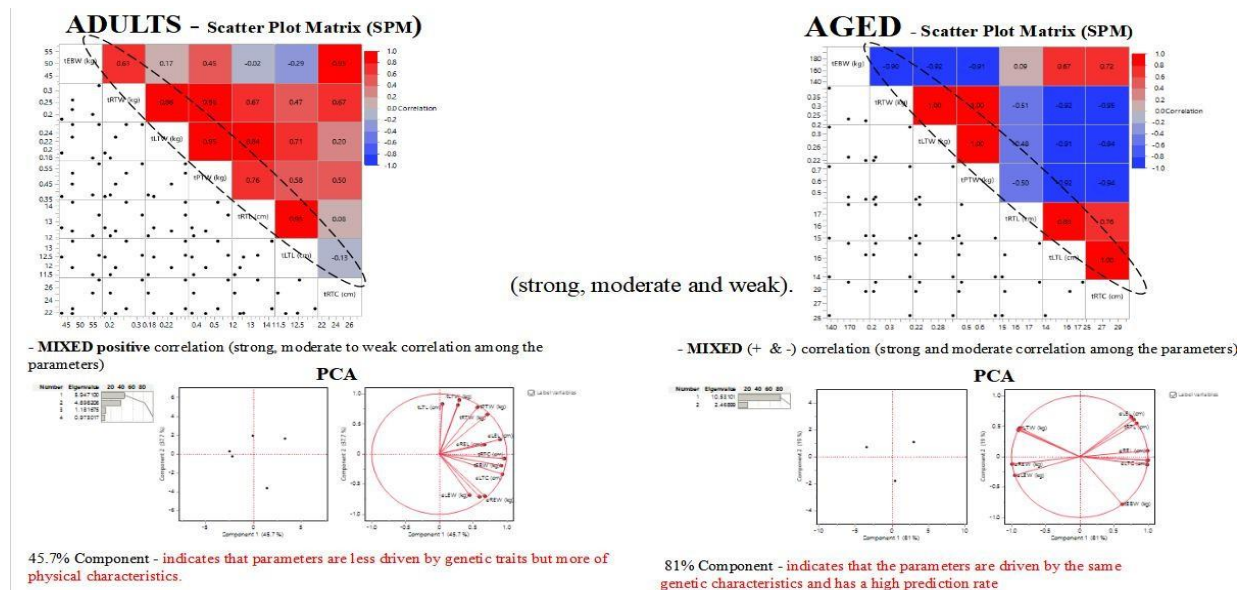


Figure 4. Scatter plot matrices and Principal Component Analyses of adult and aged correlative analysis of testicular biomorphometric parameters of different age groups of boars. Note: the mixed correlation profiles existing among testicular biomorphometric parameters in adult and aged boars

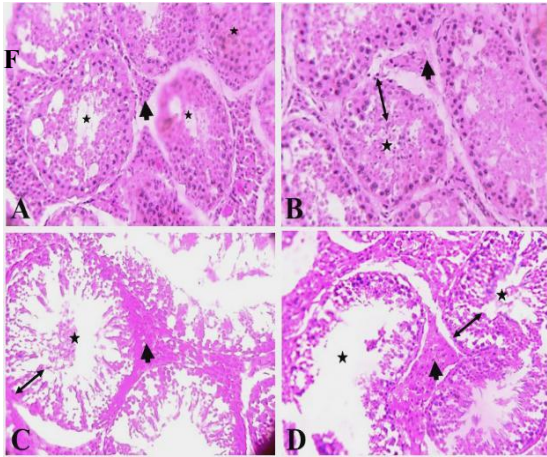


Figure 5. Photomicrographs of the Testis of Different Age Groups of the Nigerian Mixed Breed of Pigs. A. Prepubertal: B. Pubertal: C. Adult: D. Aged. Also, note the presence of substantial interstitial tissue (black arrowhead), spermatozoa in the lumen (star) and complete germ cell series on the seminiferous epithelium (double arrowhead) of B-D compared to A. Stain: H&E; Magnification: ×400.

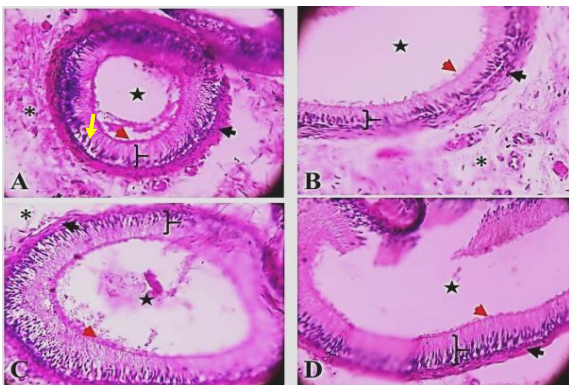


Figure 6. Photomicrographs of the caput epididymis across different age groups of Nigerian mixed-breed pigs: (A) prepubertal, (B) pubertal, (C) adult, and (D) aged. The ductal epithelium exhibits variable epithelial cell types, ranging from simple columnar (yellow arrow) to pseudostratified columnar epithelium (brace), and is lined by stereocilia (red arrowhead) of differing heights. In the prepubertal stage (A), the ductal lumen appears relatively round (star). A distinct periductal muscular coat (black arrowhead) underlies the epithelial basement membrane, while ductal interstices (asterisk) are interspersed between ducts. Stain: Hematoxylin and Eosin (H&E). Magnification: ×400.

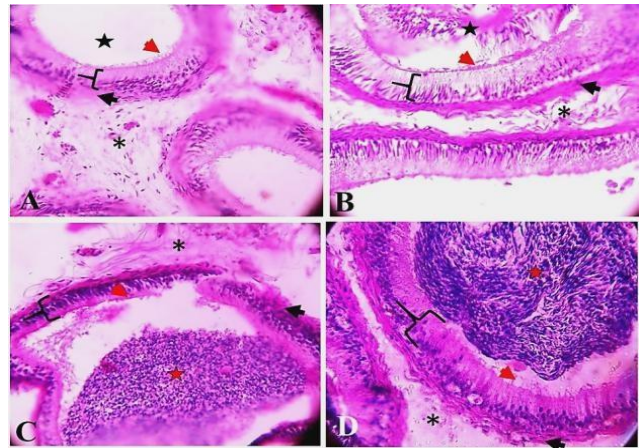


Figure 7. Photomicrographs of the corpus epididymis across different age groups of Nigerian mixed-breed pigs: (A) prepubertal, (B) pubertal, (C) adult, and (D) aged. The ductal epithelium is predominantly pseudostratified columnar (brace), lined with distinct stereocilia (red arrowhead). In the prepubertal stage (A), the ductal lumen appears round (star) and is devoid of spermatozoa, whereas in the pubertal, adult, and aged stages (B–D), the lumen is filled with abundant spermatozoa. A well-defined periductal muscular coat (black arrowhead) surrounds the ductal epithelium, and ductal interstices (asterisk) are interspersed between ducts. Stain: Hematoxylin and Eosin (H&E). Magnification: ×400.

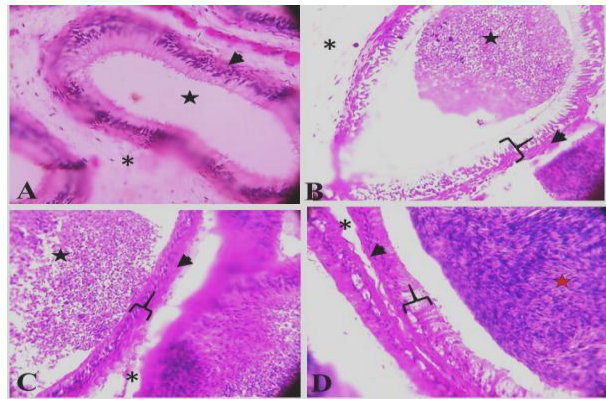
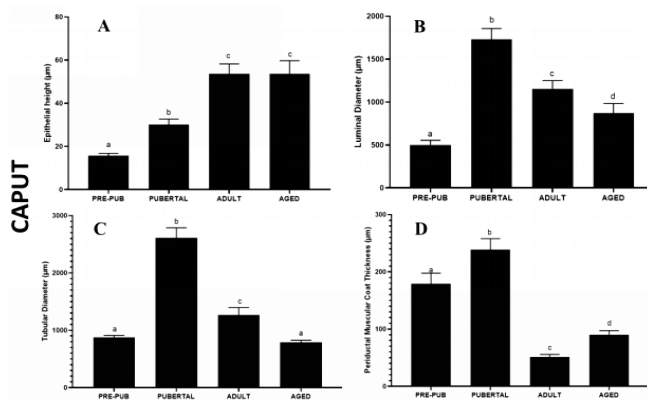
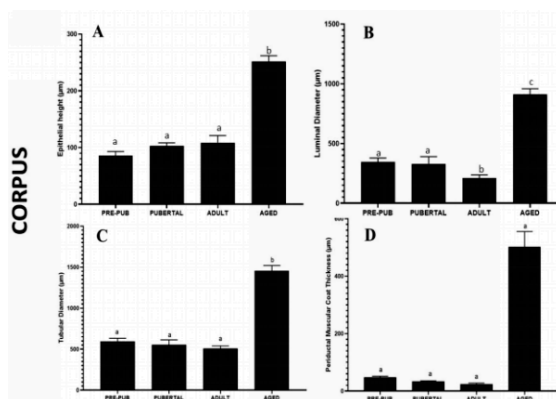
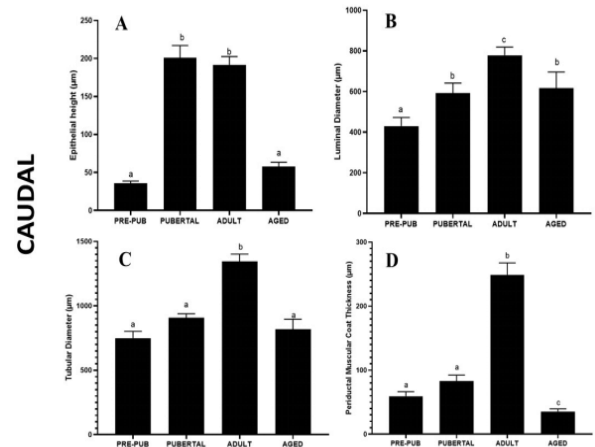


Figure 8. Photomicrographs of the cauda epididymis across different age groups of Nigerian mixed-breed pigs: (A) prepubertal, (B) pubertal, (C) adult, and (D) aged. The ductal epithelium is predominantly pseudostratified low columnar (brace), lined with distinct stereocilia (black arrowhead). In the prepubertal stage (A), the ductal lumen (star) appears round and is devoid of spermatozoa, whereas in the aged stage (D), the lumen is filled with copious spermatozoa. A well-defined periductal muscular coat (black arrowhead) surrounds the ductal epithelium, and ductal interstices (asterisk) are interspersed between ducts. Stain: Hematoxylin and Eosin (H&E). Magnification: ×400.

Table 2. Age-related Changes in the Testicular Histomorphometric Parameters of the Nigerian Mixed Breed of Pigs.

	SEH (μm)	SLD (μm)	STD (μm)
PRE-PUB	36.59 $\pm$ 4.72a	186.21 $\pm$ 30.61a	323.92 $\pm$ 35.16a
PUBERTAL	46.36 $\pm$ 4.25b	350.72 $\pm$ 31.97b	407.04 $\pm$ 35.16 b
ADULT	87.72 $\pm$ 4.07c	252.58 $\pm$ 30.61c	491.42 $\pm$ 36.72c
AGED	64.48 $\pm$ 4.99d	302.64 $\pm$ 37.49d	477.30 $\pm$ 43.06c

Values with the different alphabets (a, b, c, d) superscripts are significantly different. SEH - Seminiferous Epithelial Height, SLD - Seminiferous Luminal Diameter, STD - Seminiferous Tubular Diameter

**Figure 9.** A-D. Age-related Changes in the Caput Epididymal Histomorphometric Parameters of the Nigerian Mixed Breed of Pigs. A. Epithelial height, B. Luminal diameter C. Tubular diameter, D. Periductal Muscular Thickness. Bars with different alphabet superscripts (a, b, c, d) are significantly different.**Figure 10.** A-D. Age-related Changes in the Corpus Epididymal Histomorphometric Parameters of the Nigerian Mixed Breed of Pigs. A. Epithelial height B. Luminal diameter C. Tubular diameter. D. Periductal Muscular Thickness. Bars with different alphabet superscripts (a, b, c) are significantly different.**Figure 11.** A-D. Age-related Changes in the Cauda Epididymal Histomorphometric Parameters of the Nigerian Mixed Breed of Pigs. A. Epithelial height B. Luminal diameter C. Tubular diameter. D. Periductal Muscular Thickness. Bars with different alphabet superscripts (a, b, c) are significantly different.

Discussion

The typical creamy white coloration and regularly oval shape of the testes observed across age groups in mixed breed pigs are consistent with the report of Sunilkumar et al. (2022) on the gross morphology of crossbred Large White Yorkshire boars. The progressive age-related increase in testicular weight, with maximum body weight recorded in the prepubertal and aged groups, indicates that advancing age is accompanied by a parallel rise in testicular and body weights. This increase may be associated with enhanced cellular proliferation and greater connective tissue deposition in the organs from puberty to aging (Thomas and Raja, 1980; Schinckel et al., 1983).

Testicular biometric parameters such as length, width, and circumference, particularly testicular circumference, are recognized as reliable indirect indicators of testicular size, volume, and the onset of active spermatogenesis (Bongso et al., 1982). The marked age-related increase in these parameters likely reflects morphological adaptations required to sustain changing reproductive functions with age.

The pronounced reduction in testiculo-somatic weight (TSW) observed in aged pigs suggests a negative correlation between testicular weight and increasing body weight. This relationship may be linked to the progressive decline in the functional capacity of testicular parenchyma in older pigs. Reduced testicular weight relative to body weight may also reflect diminished androgen levels in aging animals (Borg et al., 1993; Park and Yi, 2002). The age-related increase in testicular biometric parameters aligns with the findings of Ferreira et al. (2013), who reported similar changes in wild boars from birth to 12 months, indicating morphological adjustments to meet evolving reproductive demands.

In prepubertal pigs, testicular biomorphometric parameters exhibited the strongest positive correlations, with principal component analysis (PCA) accounting for nearly 88% of the observed variation. Elevated PCA values underscore the predominant role of intrinsic

developmental processes in early testicular growth, consistent with findings reported by Zhao et al. (2024). During this stage, the parameters remain closely aligned and minimally influenced by external factors, indicating that prepuberty may represent the most reliable window for assessing reproductive development.

The crescent-shaped epididymis corresponded with features described by Guyonnet et al. (2009) in adult boars, facilitating firm attachment to the elliptical testis. The progressive increase in epididymal weight across age groups may reflect compensatory growth with advancing age. However, the significant decline in epididymal somatic weight in older pigs, consistent with Adebayo and Olurode (2010), may result from reduced spermatogenic content within the lumen. Age-related increases in epididymal length and width mirrored the changes observed in testicular biometric parameters (Oyeyemi and Ubiogoro, 2005; Evans, 2009; Olukole and Oke, 2016).

Small seminiferous tubular lumina lacking spermatozoa in prepubertal pigs provided structural evidence of a quiescent reproductive state. The simple columnar epithelial lining of the epididymis in prepubertal pigs, compared with the classical pseudostratified stereociliated columnar epithelium in older pigs, indicated ongoing epithelial differentiation in younger animals and complete maturation in adults. This observation agrees with Hannema and Hughes (2006) and Rodríguez et al. (2002), who noted that postnatal epididymal development involves extensive remodeling characterized by ductal elongation and convolution. At puberty, the epididymis becomes fully differentiated, forming a highly convoluted channel lined with diverse epithelial cell types.

The significant increase in seminiferous epithelial height observed in adult pigs is consistent with reports in Datong yak, Assam goats, and Tokara goats (Kalwar et al., 2019; Sarma and Devi, 2017; Nishimura et al., 2000). This increase has been linked to enhanced sperm production in adult pigs (Russell et al., 1990). In contrast, the reduced seminiferous luminal diameter in prepubertal pigs reflected the absence of spermatozoa and corroborated the findings of Zheng et al. (2022). The enlargement of seminiferous tubular diameter in adults compared to younger groups may be attributed to rapid tubular development prior to sexual maturity and intensified spermatogenesis, consistent with Ibrahim et al. (2013) and Kalwar et al. (2019).

The marked increase in caput epithelial height in adult and aged pigs suggested a higher proportion of principal cells, which transition from tall columnar in the caput to shorter columnar forms in the corpus and cauda. This observation aligns with Jianwu et al. (2021). Enlargement of caput epididymal luminal and tubular diameters, along with thickening of the periductal muscle coat in pubertal pigs, reflects substantial expansion of epididymal smooth muscle, accentuated by epithelial folding.

Similarly, the consistent increase in epithelial height, luminal and tubular diameters, and periductal muscle thickness in the cauda epididymis of adult and aged pigs corresponded with findings in domestic pigs (Ferial and Wolfgang, 2024). In contrast, the reduced epithelial height in the cauda epididymis of prepubertal pigs likely

reflects an undifferentiated epithelium and the limited epithelial folding characteristic of this age group.

It is concluded from this study that mixed Nigerian local-exotic boars displayed a clear age-dependent trajectory in reproductive development, progressing from a quiescent prepubertal phase to functional maturity marked by the presence of a complete germ cell series. Although biometric indices increased with age, the decline in relative testiculo-somatic and epididymo-somatic weights in older animals indicated a shift in physiological investment during later life. The strong correlations among testicular biomorphometric parameters in the prepubertal stage highlighted this period as a critical window for predicting future breeding potential. Histological evidence further confirms that reproductive maturation peaks in adulthood, with maximal seminiferous epithelial height supporting heightened spermatogenic activity. Collectively, these findings provide valuable baseline data for improving veterinary diagnostics and advancing sustainable livestock productivity.

Limitation of the study

A limitation of the present study is the relatively small sample size ($n=4$ animals per group), which may limit the generalizability of the findings and reduce statistical power for detecting subtle age-related differences. Nevertheless, the study provides baseline information on testicular and epididymal histomorphometry in pigs and offers a foundation for future studies involving larger populations.

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Conflict of Interest

There is no conflict of interest regarding this work.

Authors' Contributions

OJO: Conceptualized, supervised, validated, funded the research, and wrote the initial draft. **PNJ:**

Supervised, validated, and contributed to funding. **TJ:** Supervised and contributed to funding. **AOM:** Validated and analyzed the raw data generated from the study, reviewed and edited the manuscripts. **GIJ:** Reviewed and edited the manuscripts. **AIA:** Reviewed and edited the manuscripts. **UES:** Facilitated sample collection, reviewed and edited manuscripts. **MBM & HSA:**

Reviewed and edited the manuscripts. All authors have read and approved the final version of the manuscript for publication in the present journal.

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