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Osteometric assessment of caponized and intact cockerels fed different protein sources

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ABSTRACT

Aim: The aim of the study was to evaluate the osteometric parameters of Noiler and Black Harco cockerels subjected to four different dietary protein sources over a period of 13 weeks.
Materials and Methods: A total of 240 cockerels, comprising both caponized and intact birds, were randomly assigned to four dietary treatments using a Randomized Complete Block Design (RCBD). The effects of different protein sources on bone development were assessed through various osteometric measurements, including weight, length, and diameters of the tibia and femur.
Results: Significant differences in skeletal development were observed across the treatment groups. In un-caponized Noiler, Treatment 1 had the highest live weight (3.11 kg) and tibia weight (36.71 g), while Treatment 4 had the lowest (2.61 kg and 20.41 g, respectively). Caponized Noiler had the heaviest tibia in Treatment 2 (38.61 g). For intact Black Harco, the largest femur (18.31g) was in Treatment 1, while Treatment 2 had the least weight of 15.21g. Caponized Black Harco recorded the widest tibia midshaft diameter (8.61 mm) in Treatment 3, compared to the least value of 7.71mm in Treatment 2.
Conclusion: It was concluded that both dietary protein sources and caponization significantly affected bone growth in Noiler and Black Harco cockerels. Specific protein source combinations contributed to improved skeletal structure, suggesting their potential for optimizing cockerel performance and welfare.

Keywords: Black Harco, caponization, cockerels, Noiler, osteometric assessment

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Introduction

Low protein consumption remains a significant challenge in many developing nations, including Nigeria, primarily due to poverty, overpopulation and limited access to affordable animal protein sources (Akinwumi *et al*., 2012). The demand for animal protein has continued to rise, emphasizing need for fast-growing, high-yielding livestock to bridge protein gap (Oladunjoye *et al*., 2018). Cockerel production presents an efficient solution to this crisis, offering advantages such as increased growth rates, improved feed conversion efficiency and widespread consumer acceptance (Ekunseitan *et al*., 2017).

However, ensuring optimal cockerel performance requires meeting nutritional demands, particularly protein requirements, which are crucial for muscle development and skeletal integrity (Adebiyi *et al*., 2021). Given the escalating costs of feed ingredients and the ban on the importation of certain animal products, exploring the major protein sources in cockerel diets has become imperative for sustainable production in Nigeria (Adeyeye *et al*., 2020).

The choice of protein source, whether plant-based (soybean meal, groundnut cake, palm kernel meal) or animal-derived (fishmeal, blood meal, maggot meal), significantly influences growth, carcass traits, and skeletal development (Omage *et al*., 2019). Research has established that dietary protein directly affects bone mineralization, bone strength, and mechanical properties, making it a critical component of poultry diets (Akinola *et al*., 2023). While plant proteins are more readily available and cost-

effective, they often contain anti-nutritional factors that reduce protein digestibility and nutrient absorption (Ojo *et al*., 2017). Conversely, animal proteins are nutrient-dense and highly digestible but remain expensive and sometimes unavailable due to market restrictions (Adeyeye *et al*., 2021). Identifying the most efficient and cost-effective protein source is essential to optimizing poultry performance, particularly in Nigeria's evolving poultry industry.

Caponization, the surgical removal of testes in male chickens, is a management strategy to enhance meat quality, growth performance, and feed efficiency (Ajayi *et al*., 2015). The procedure alters hormonal balance, directing more energy toward muscle accretion and fat deposition, resulting in tender, high-quality meat (Olawumi *et al*., 2016). Studies have shown that caponization significantly influences growth and carcass traits, with variations depending on breed, age at surgery, and dietary factors (Aikpitanyi *et al*., 2020). However, caponization also affects skeletal development, with some studies reporting reduced bone mineral density and mechanical strength, while others suggest minimal or no effect on bone parameters (Ojediran *et al*., 2018). The removal of androgens post-caponization has been linked to alterations in bone metabolism, but the extent of these changes varies depending on diet composition, breed, and environmental factors (Obun *et al*., 2022).

Noiler and Black Harco cockerels have gained prominence in Nigeria's poultry sector due to their hardiness, and adaptability. Noiler, a hybrid meat breed, are fast-growing, reaching market size within three to four months under optimal conditions. They exhibit multi-coloured plumage, ranging from black and white to brown speckled feathers, and thrive in various rearing systems, including free-range and semi-intensive farming (Akinwumi *et al*., 2012). Their ability to utilize unconventional feedstuffs, including household leftovers, makes them a preferred choice for smallholder farmers (Ojo *et al*., 2017). In contrast, Black Harco cockerels, also called "gentle giants," are larger birds, standing between 24–32 inches tall and weighing approximately 4 kg. They have black plumage with an iridescent sheen under sunlight and are noted for their calm temperament and high feed intake capacity (Adeyeye *et al*., 2020). Both breeds exhibit strong adaptability to various climatic conditions, making them suitable for diverse poultry farming systems across Nigeria (Obun *et al*., 2022).

This research is significant as it addresses a gap in current knowledge on how dietary protein sources and caponization interact to influence bone development in two increasingly important indigenous poultry breeds. By combining osteometric evaluation with breed-specific and nutritional variables, the study offers practical insights that could help farmers make informed decisions on diet formulation and management practices. These findings have the potential to improve meat quality, animal welfare, and production efficiency, contributing to the broader goal of food security in Nigeria.

Therefore, the aim of this study was to evaluate the osteometric parameters of caponized and intact Noiler and Black Harco cockerels fed four different dietary protein sources over a 13-week period. The study specifically examined the effects of protein source and caponization on skeletal characteristics such as bone weight, length, and diameter of the tibia and femur.

Materials and Methods

Experimental location and climate

The 13-week experiment was conducted at the Poultry Unit of the Teaching and Research Farm, Faculty of Agriculture, Ambrose Alli University, located in Ekpoma, Esan West Local Government Area, Edo State, Nigeria. The Poultry Unit is approximately 6.80°E longitude and 6.44°N latitude within Nigeria's south-south geopolitical zone. The region experiences a tropical climate, with an average annual rainfall of around 1,556 mm. Ambient temperatures typically range from 26°C in December to 34°C in February, while relative humidity varies from 6% in January to 92% in August, averaging about 82% throughout the year.

Housing and Bird Management

The birds were housed in a deep litter system with an open-sided poultry house, where wooden partitions separated individual pens. The pens were thoroughly cleaned and disinfected, followed by spreading wood shavings on the floor to provide bedding. Drinkers and feeders were placed in the pens, with the drinkers set slightly above the ground to minimize contamination from dirt and droppings.

The birds, acquired from a reputable farm at six weeks of age, were given access to commercial feed and water upon arrival and fed *ad libitum*. Throughout experimental period, proper sanitary measures and recommended medications and vaccinations were strictly followed. Routine management practices were consistently carried out, including daily cleaning of feeders and drinkers and weekly litter replacement.

Feeding: During initial two-week acclimatization period, the birds were fed a commercial grower diet from a trusted feed vendor in Ekpoma, Edo State, Nigeria. Following caponization, the birds were switched to a formulated finisher diet. The experimental diets consisted of four different protein sources: Diet 1 included groundnut seed cake (GNC) with fish meal, Diet 2 had groundnut seed cake (GNC) without fish meal, Diet 3 had cottonseed cake (CSC), and Diet 4 contained palm kernel seed cake (PKC).

The ingredients for four diets used in the study were sourced from a reputable animal feed dealer in Ekpoma, Edo State, Nigeria. Moringa leaves (*Moringa oleifera*) were collected from various locations in Ekpoma, Edo State. The collected moringa leaves were air-dried for one week to reduce moisture content. Once thoroughly dried, the leaves were ground into a powder and stored in airtight containers until their inclusion in the formulated diets.

Experimental Design and Duration: The study involved 240 birds, comprising both Black Harco and Noiler breeds, in a randomized complete block design (RCBD). Sixty (60) birds were allocated to each treatment group, including caponized and intact (uncaponized) birds. Each treatment was replicated three times, with ten (10) birds per replicate. The feeding trial commenced immediately after caponization, when the birds were eight weeks old, and continued for 12 weeks, concluding when birds reached 20 weeks of age.

Surgical Caponization: Birds selected for caponization received antibiotics one week before the procedure. They were fasted for 24 hours from feed and 12 hours from water to reduce microbial activity in gastrointestinal tract and minimize intestinal swelling, allowing for easier identification of the testes during surgery. The materials used included a table, surgical knife, rib spreader, forceps, cotton wool and ethanol.

The surgical procedure took place under direct lighting. The birds were restrained on a table, with their wings and legs secured to minimize movement. Feathers were plucked from the rib area to expose the skin. An incision was made between the last two ribs, wide enough for rib spreader to be inserted, allowing the ribs to be held apart to locate the testes. Once located, the testes were carefully removed with forceps, and the tissue was gently twisted to control bleeding. The incision was cleaned with ethanol and covered with cotton wool. The procedure was repeated on the other side, and the bird was treated with antibiotics for one-week post-operation to prevent infection.

During the recovery period, some birds developed air sacs under the skin at the incision site. This condition was managed by carefully puncturing the skin with a needle to release the accumulated air.

Osteometric Parameters Measurement: After the feeding trial, three intact and three caponized cockerels from each treatment were slaughtered and plucked to assess osteometric parameters. The weight and length of the tibia and femur were meticulously recorded to evaluate skeletal development. The bones were carefully dissected from the hind limbs, ensuring the complete removal of soft tissues to prevent measurement inaccuracies.

A high-precision scale was used to determine tibia and femur weight. Each tibia and femur were individually placed on the scale, and the readings were recorded in grams. Measurements were taken in a controlled environment to eliminate potential interferences, such as air currents or vibrations that could potentially affect precision. Following this, the relative tibia and femur weights were calculated as a percentage of the live body weight of the birds.

Relative Bone Weight (%) = (Bone Weight (g) / Live Body Weight (g)) × 100

For length measurements, a digital Vernier calliper was employed to ensure precise readings in millimetres. The bones were positioned on a flat surface, and the measuring instrument was aligned carefully along the longest axis of each bone. Multiple readings were taken for each sample to enhance accuracy and minimize errors due to minor variations in placement.

Table 1. Gross composition of formulated diets

Feed ingredients (%)	T1 Diet 1	T2 Diet 2	T3 Diet 3	T4 Diet 4
Maize	47.00	47.00	47.00	37.00
Moringa	1.50	1.50	1.50	1.50
Wheat offal	13.00	10.50	8.50	10.00
GNC (Groundnut seed cake)	10.00	11.00	-	-
CSC (cotton seed cake)	-	-	18.00	-
PKC(palm kernel seed cake)	-	-	-	26.50
Brewer's spent grain (BSG)	24.00	27.00	22.00	22.00
Fishmeal	1.50	-	-	-
Dicalcium phosphate	1.50	1.50	1.50	1.50
Limestone	1.00	1.00	1.00	1.00
Salt	0.25	0.25	0.25	0.25
Premix	0.25	0.25	0.25	0.25
Crude protein Kcal/kg	2494.78	2493.78	2489.35	2470.23

Data collected from the experiment were subjected to a one-way analysis of variance (ANOVA) using SAS software to determine significant differences among treatments. When significant treatment effects ($P < 0.05$) were detected, Duncan's Multiple Range Test (DMRT) was applied for mean separation, following the methodology of Steel and Torrie (1997). Before analysis, data were tested for normality (Shapiro-Wilk test) and homogeneity of variance (Levene's test) to confirm the appropriateness of ANOVA assumptions. This experiment's statistical significance was set at $P < 0.05$, while highly significant effects were considered at $P < 0.01$.

Results and Discussion

It was presented the bone analysis of un-caponized Noiler cockerels fed four different protein sources (Table 2). The results indicate that Treatment 1 recorded the highest live weight (3110.00 g), significantly different from the other treatments, with Treatment 4 having the lowest (2610.00 g).

Treatment 1 recorded highest tibia weight (36.71 g) and longest tibia (155.60 mm), whereas Treatment 2 had lowest values (27.21 g, 153.11 mm, respectively). The highest relative tibia weight (1.19%) was observed in Treatment 3, while Treatment 2 had the lowest (1.02%). Tibia extremity diameters varied, with Treatment 2 having the widest top extremity (33.21 mm) and Treatment 1 narrowest (26.61 mm). The widest bottom extremity (20.41 mm) was recorded in Treatment 3, whereas Treatment 4 had smallest (17.11 mm). Tibia midshaft diameter was greatest in Treatment 1 (13.21 mm) and smallest in Treatment 2 (9.51 mm).

For femur parameters, Treatment 2 exhibited the highest femur weight (23.41 g), whereas Treatment 4 had lowest (20.41 g). Relative femur weight was greatest in Treatment 2 (0.88%) and lowest in Treatment 1 (0.73%). Femur length was longest in Treatment 4 (110.01 mm) and shortest in Treatment 1 (104.23 mm). Femur extremity diameters showed Treatment 1 with the widest top extremity (26.81 mm), while Treatment 3 had the smallest (24.61 mm). The widest bottom extremity (24.31 mm) was found in Treatment 3, whereas Treatment 2 had the narrowest (22.01 mm). Femur midshaft diameter was widest in Treatment 1 (10.91 mm) and narrowest in Treatment 2 (9.91 mm). It was recorded bone analysis of caponized Noiler cockerels fed four different protein sources (Table 3). The results indicate that Treatment 2 recorded highest live weight (3260.00 g), whereas Treatment 3 had lowest (2510.00 g).

Treatment 2 had highest tibia weight (38.61 g) and relative tibia weight (1.18%), whereas Treatment 3 had the lowest values (14.11 g, 0.56%). Tibia length was longest in Treatment 3 (154.41 mm), slightly exceeding Treatment 2 (154.13 mm). Tibia extremity diameters varied, with Treatment 3 having the widest top (34.41 mm) and bottom (19.01 mm) diameters, while Treatment 1 had the narrowest bottom extremity (17.11 mm). Tibia midshaft diameter was widest in Treatment 1 (11.61 mm) and narrowest in Treatment 4 (10.21 mm).

For femur parameters, Treatment 2 had the heaviest femur (25.81 g), while Treatment 4 had the lightest (18.71 g). Relative femur weight was highest in Treatment 3 (0.91%) and lowest in Treatment 1 (0.68%). Femur length was longest in Treatment 3 (113.71 mm) and shortest in Treatment 1 (104.81 mm). Femur extremity diameters showed Treatment 2 with widest top extremity (27.11 mm), while Treatment 1 had narrowest (22.61 mm). The widest bottom extremity (26.61 mm) was in Treatment 1, whereas Treatment 4 had smallest (22.21 mm). Femur midshaft diameter was widest in Treatment 2 (10.91 mm) and smallest in Treatment 3 (9.61 mm).

Table 2. Bone analysis of Noiler cockerels (uncaponized)

Bone parameters	T1	T2	T3	T4
Live weight (g)	$3110^{a} \pm 0.10$	$2660^{b} \pm 0.01$	$2700^{b} \pm 0.10$	$2610^{b} \pm 0.01$
Tibia weight (g)	$36.71^{a} \pm 0.01$	$27.21^{d} \pm 0.01$	$32.21^{b} \pm 0.01$	$28.11^{c} \pm 0.01$
Relative Tibia Weight (%)	$1.18^{a} \pm 0.00$	$1.02^{b} \pm 0.00$	$1.19^{a} \pm 0.04$	$1.08^{b} \pm 0.00$
Tibia Length (mm)	$155.60^{a} \pm 0.01$	$153.11^{c} \pm 0.01$	$154.21^{b} \pm 0.01$	$154.71^{b} \pm 0.01$
Tibia Extremety diameter (top)(mm)	$26.61^{d} \pm 0.01$	$33.21^{a} \pm 0.01$	$30.81^{b} \pm 0.01$	$27.71^{c} \pm 0.01$
Tibia Extremety diameter(bottom)(mm)	$18.51^{b} \pm 0.01$	$18.61^{b} \pm 0.01$	$20.41^{a} \pm 0.01$	$17.11^{c} \pm 0.01$
Tibia Midshaft diameter (mm)	$13.21^{a} \pm 0.01$	$9.51^{b} \pm 0.01$	$9.61^{b} \pm 0.01$	$10.01^{b} \pm 0.01$
Femur Weight (g)	$22.91^{b} \pm 0.01$	$23.41^{a} \pm 0.01$	$21.51^{c} \pm 0.01$	$20.41^{d} \pm 0.01$
Relative Femur Weight (%)	$0.73^{c} \pm 0.00$	$0.88^{a} \pm 0.00$	$0.79^{b} \pm 0.03$	$0.78^{bc} \pm 0.00$
Femur Length (mm)	$104.23^{c} \pm 0.01$	$108.61^{b} \pm 0.01$	$104.71^{c} \pm 0.01$	$110.01^{a} \pm 0.01$
Femur Extremety diameter (top)(mm)	26.81a ± 0.01	26.01b ± 0.01	24.61d ± 0.01	25.61c ± 0.01
Femur Extremety diameter (bottom)(mm)	23.31b ± 0.01	22.01c ± 0.01	24.31a ± 0.01	23.01b ± 0.01
Femur Midshaft diameter (mm)	$10.91^{a} \pm 0.01$	$9.91^{d} \pm 0.01$	$10.41^{b} \pm 0.01$	$10.61^{ab} \pm 0.01$

a,b,c,d; means in the same row with different superscript are significantly different ($p<0.05$)

Table 3. Bone analysis of caponized Noiler cockerels fed different protein sources

Bone parameters	**T1**	**T2**	**T3**	**T4**
Live weight (g)	$3110^{b} \pm 0.10$	$3260^{a} \pm 0.01$	$2510^{d} \pm 0.10$	$2610^{c} \pm 0.01$
Tibia weight (g)	$30.07^{b} \pm 0.01$	$38.61^{a} \pm 0.01$	$14.11^{d} \pm 0.01$	$29.71^{c} \pm 0.01$
Relative Tibia Weight (%)	$0.96^{c} \pm 0.00$	$1.18^{a} \pm 0.00$	$0.56^{d} \pm 0.00$	$1.14^{ab} \pm 0.00$
Tibia Length (g)	$154.31^{ab} \pm 0.01$	$154.13^{bc} \pm 0.01$	$154.41^{a} \pm 0.01$	$154.21^{ab} \pm 0.01$
Tibia Extremity diameter (top)(mm)	$26.61^{c} \pm 0.01$	$30.51^{b} \pm 0.01$	$34.41^{a} \pm 0.01$	$25.51^{d} \pm 0.01$
Tibia Extremity diameter(bottom)(mm)	$17.11^{c} \pm 0.01$	$17.31^{bc} \pm 0.01$	$19.01^{a} \pm 0.01$	$17.71^{b} \pm 0.01$
Tibia Midshaft diameter (mm)	$11.61^{a} \pm 0.01$	$11.31^{a} \pm 0.01$	$10.51^{b} \pm 0.01$	$10.21^{b} \pm 0.01$
Femur Weight (g)	$21.21^{c} \pm 0.01$	$25.81^{a} \pm 0.01$	$23.01^{b} \pm 0.01$	$18.71^{d} \pm 0.01$
Relative Femur Weight (%)	$0.68^{d} \pm 0.00$	$0.79^{b} \pm 0.00$	$0.91^{a} \pm 0.03$	$0.72^{c} \pm 0.00$
Femur Length (mm)	$104.81^{d} \pm 0.01$	$112.71^{b} \pm 0.01$	$113.71^{a} \pm 0.01$	$106.71^{c} \pm 0.01$
Femur Extremity diameter (top)(mm)	$22.61^{d} \pm 0.01$	$27.11^{a} \pm 0.01$	$25.31^{b} \pm 0.01$	$27.71^{a} \pm 0.01$
Femur Extremity diameter (bottom)(mm)	$26.61^{a} \pm 0.01$	$25.81^{b} \pm 0.01$	$26.01^{a} \pm 0.01$	$22.21^{c} \pm 0.01$
Femur Midshaft diameter (mm)	$10.11^{b} \pm 0.01$	$10.91^{a} \pm 0.01$	$9.61^{c} \pm 0.01$	$10.61^{a} \pm 0.01$

a,b,c,d; means in the same row with different superscript are significantly different ($p<0.05$)

Table 4. Bone analysis of Black Harco cockerels (intact/uncaponized)

Bone parameters	T1	T2	T3	T4
Live weight (g)	$2010^{a} \pm 0.01$	$1710^{b} \pm 0.01$	$1610^{c} \pm 0.10$	$1710^{b} \pm 0.01$
Tibia weight (g)	$25.11^{a} \pm 0.01$	$16.91^{d} \pm 0.01$	$18.51^{c} \pm 0.01$	$20.21^{b} \pm 0.01$
Relative Tibia Weight (%)	$1.25^{ab} \pm 0.01$	$0.99^{c} \pm 0.01$	$1.50^{b} \pm 0.01$	$1.18^{a} \pm 0.01$
Tibia Length (mm)	$147.61^{b} \pm 0.01$	$141.51^{d} \pm 0.01$	$148.81^{a} \pm 0.01$	$146.81^{c} \pm 0.01$
Tibia Extremety diameter (top)(mm)	$26.91^{a} \pm 0.01$	$24.71^{b} \pm 0.01$	$22.91^{d} \pm 0.01$	$23.91^{c} \pm 0.01$
Tibia Extremety diameter (bottom)(mm)	$16.11^{a} \pm 0.01$	$16.31^{a} \pm 0.01$	$15.11^{b} \pm 0.01$	$12.41^{c} \pm 0.01$
Tibia Midshaft diameter(mm)	$8.21^{b} \pm 0.01$	$7.51^{c} \pm 0.01$	$8.41^{b} \pm 0.01$	$9.41^{a} \pm 0.01$
Femur Weight(g)	$18.31^{a} \pm 0.01$	$15.21^{d} \pm 0.01$	$16.91^{c} \pm 0.01$	$17.31^{b} \pm 0.01$
Relative Femur Weight (%)	$0.91^{b} \pm 0.00$	$0.89^{c} \pm 0.00$	$1.05^{a} \pm 0.01$	$1.01^{a} \pm 0.01$
Femur Length (mm)	$106.01^{a} \pm 0.01$	$98.91^{c} \pm 0.01$	$92.11^{d} \pm 0.01$	$99.91^{b} \pm 0.01$
Femur Extremety diameter (top)(mm)	$24.51^{a} \pm 0.01$	$23.01^{b} \pm 0.01$	$22.11^{c} \pm 0.01$	$21.91^{d} \pm 0.01$
Femur Extremety diameter (bottom)(mm)	$19.51^{b} \pm 0.01$	$17.61^{c} \pm 0.01$	$22.31^{a} \pm 0.01$	$17.41^{c} \pm 0.01$
Femur Midshaft diameter (mm)	$9.91^{a} \pm 0.01$	$9.31^{b} \pm 0.01$	$8.81^{c} \pm 0.01$	$10.01^{a} \pm 0.01$

It was recorded the bone analysis of un-caponized Black Harco cockerels fed four different protein sources (Table 4). The results indicate that Treatment 1 recorded the highest live weight (2010.00 g), while Treatment 3 had the lowest (1610.00 g). Significant differences were observed across treatments for this parameter.

Treatment 1 recorded the highest tibia weight (25.11 g), while Treatment 2 had the lowest (16.91 g). Relative tibia weight was highest in Treatment 3 (1.50%) and lowest in Treatment 2 (0.99%). Tibia length was longest in Treatment 3 (148.81 mm) and shortest in Treatment 2 (141.51 mm). Tibia extremity diameters varied, with Treatment 1 having the widest top extremity (26.91 mm) and Treatment 3 the narrowest (22.91 mm). The bottom extremity diameter was widest in Treatment 2 (16.31 mm) and smallest in Treatment 4 (12.41

mm). Tibia midshaft diameter was highest in Treatment 4 (9.41 mm) and lowest in Treatment 2 (7.51 mm).

For femur parameters, Treatment 1 exhibited the highest femur weight (18.31 g), while Treatment 2 had the lowest (15.21 g). Relative femur weight was highest in Treatment 3 (1.05%) and lowest in Treatment 2 (0.89%). Femur length was longest in Treatment 1 (106.01 mm) and shortest in Treatment 3 (92.11 mm). Femur extremity diameters showed Treatment 1 with the widest top extremity (24.51 mm) and Treatment 4 with the narrowest (21.91 mm). The widest bottom extremity (22.31 mm) was in Treatment 3, whereas Treatment 4 had the smallest (17.41 mm). Femur midshaft diameter was highest in Treatment 4 (10.01 mm) and lowest in Treatment 3 (8.81 mm).

It was recorded the bone analysis results for caponized Black Harco cockerels fed four different protein sources (Table 5). The results indicate that Treatments 1 and 2 recorded the highest live weight (1910.00 g), while Treatments 3 and 4 had significantly lower values (1510.00 g).

Table 5. Bone analysis for caponized black Harco cockerels

Bone parameters	T1	T2	T3	T4
Live weight (g)	$1910^{a} \pm 0.01$	$1910^{a} \pm 0.01$	$1510^{b} \pm 0.10$	$1510^{b} \pm 0.01$
Tibia weight (g)	$17.81^{c} \pm 0.01$	$18.31^{b} \pm 0.01$	$16.21^{d} \pm 0.01$	$20.51^{a} \pm 0.01$
Relative Tibia Weight (%)	$0.93^{bc} \pm 0.00$	$0.96^{bc} \pm 0.00$	$1.07^{b} \pm 0.01$	$1.35^{a} \pm 0.01$
Tibia Length (mm)	$145.11^{a} \pm 0.01$	$144.51^{b} \pm 0.01$	$136.21^{d} \pm 0.01$	$138.31^{c} \pm 0.01$
Tibia Extremity diameter (top) (mm)	$24.91^{d} \pm 0.01$	$25.71^{c} \pm 0.01$	$28.31^{a} \pm 0.01$	$26.41^{b} \pm 0.01$
Tibia Extremity diameter(bottom)(mm)	$16.81^{a} \pm 0.01$	$15.81^{b} \pm 0.01$	$14.61^{c} \pm 0.01$	$16.91^{a} \pm 0.01$
Tibia Midshaft diameter (mm)	$8.41^{a} \pm 0.01$	$7.71^{d} \pm 0.01$	$8.61^{a} \pm 0.01$	$8.51^{a} \pm 0.01$
Femur Weight (mm)	$16.41^{b} \pm 0.01$	$18.81^{a} \pm 0.01$	$14.31^{d} \pm 0.01$	$15.21^{c} \pm 0.01$
Relative Femur Weight (%)	$0.86^{d} \pm 0.00$	$0.98^{ab} \pm 0.00$	$0.95^{ab} \pm 0.01$	$1.01^{a} \pm 0.01$
Femur Length (mm)	$100.01^{a} \pm 0.01$	$99.51^{b} \pm 0.01$	$91.81^{d} \pm 0.01$	$94.01^{c} \pm 0.01$
Femur Extremety diameter (top) (mm)	$24.51^{a} \pm 0.01$	$22.31^{b} \pm 0.01$	$21.81^{c} \pm 0.01$	$22.31^{b} \pm 0.01$
Femur Extremety diameter (bottom)(mm)	$23.21^{a} \pm 0.01$	$22.11^{b} \pm 0.01$	$20.11^{c} \pm 0.01$	$17.51^{d} \pm 0.01$
Femur Midshaft diameter (mm)	$8.41^{c} \pm 0.01$	$9.31^{a} \pm 0.01$	$8.71^{b} \pm 0.01$	$8.71^{b} \pm 0.01$

a,b,c,d; means in the same row with different superscript are significantly different ($p<0.05$)

Treatment 4 had the highest tibia weight (20.51 g) and relative tibia weight (1.35%), while Treatment 3 recorded the lowest values (16.21 g, 0.93%). Tibia length was longest in Treatment 1 (145.11 mm) and shortest in Treatment 3 (136.21 mm). Tibia extremity diameters varied, with Treatment 3 having the widest top extremity (28.31 mm) and Treatment 1 the narrowest (24.91 mm). The widest bottom extremity (16.91 mm) was found in Treatment 4, whereas Treatment 3 had the smallest (14.61 mm). Tibia midshaft diameter was greatest in Treatment 3 (8.61 mm) and smallest in Treatment 2 (7.71 mm).

For femur parameters, Treatment 2 had the highest femur weight (18.81 g), while Treatment 3 had the lowest (14.31 g). Relative femur weight was greatest in Treatment 4 (1.01%) and lowest in Treatment 1 (0.86%). Femur length was longest in Treatment 1 (100.01 mm) and shortest in Treatment 3 (91.81 mm). Femur extremity diameters showed Treatment 1 with the widest top extremity (24.51 mm) and Treatment 3 with the narrowest (21.81 mm). The widest bottom extremity (23.21 mm) was in Treatment 1, whereas Treatment 4 had the smallest (17.51 mm). Femur midshaft diameter was highest in Treatment 2 (9.31 mm), while Treatments 3 and 4 had slightly lower but similar values (8.71 mm).

The significant differences observed in live weights among caponized and un-caponized Noiler and Black Harco cockerels across treatments may be attributed to the physiological effects of caponization. This procedure eliminates the influence of male sex hormones, leading to reduced physical activity, improved feed conversion efficiency, and increased fat deposition, ultimately enhancing growth and meat quality. Jacob and Mather (2010) reported that caponized birds exhibited a 15% increase in body weight compared to intact males. Similarly, Rahman *et al*. (2004) observed that caponized chickens had a 12% higher live

weight than their un-caponized counterparts. Chen *et al*. (2006) found that caponization resulted in a significant increase in body weight, with caponized birds weighing approximately 10% more than intact males. These findings align with the present study, where caponized birds, particularly in Treatments 1 and 2, demonstrated higher live weights.

The influence of diet composition was evident in the observed growth performance across treatments. Cockerels fed diets containing groundnut seed cake (GNC) mixed with fishmeal exhibited higher live weights, indicating that this protein combination supports optimal growth. Durunna *et al*. (2006) demonstrated that broilers fed diets with GNC and fishmeal achieved a live weight of 2.5 kg at 8 weeks, surpassing those on soybean meal-based diets, which reached 2.2 kg. This suggests that GNC combined with fishmeal provides a superior amino acid profile, promoting better growth performance. Similar observations have been made in Nigerian studies, emphasizing the importance of protein quality in optimizing poultry productivity. Omeje *et al*. (2016) reported that broilers fed high-quality protein sources had a 14% increase in live weight compared to those on standard diets. Akinola *et al*. (2023) found that incorporating fishmeal into poultry diets improved growth rates by 18%.

Variations in tibia and femur lengths, extremity diameters, and midshaft diameters observed in this study further highlight the role of diet and caponization timing in skeletal development. Hsieh (2003) reported that caponized chickens had a tibia length of 12.5 cm, significantly longer than the 11.8 cm observed in un-caponized birds, suggesting that caponization delays ossification, allowing for extended bone growth. However, Fennell and Scanes (2012) observed minimal effects on tibia length when dietary protein requirements were met, with both caponized and un-caponized birds exhibiting tibia lengths around 12.0 cm. Tsay *et al*. (2004) reported no significant difference in tibia length between caponized and intact males, measuring approximately 11.9 cm in both groups. These discrepancies may be due to differences in diet formulations, caponization timing, and genetic factors.

The present study found that caponized Noiler in Treatment 2 had the highest tibia weight (38.61 g), while caponized Black Harco chickens in Treatment 2 exhibited the highest femur weight (18.81 g). These findings support previous research suggesting that caponization enhances bone mineralization and density due to hormonal changes that promote calcium and phosphorus deposition in bone tissue. Tor *et al*. (2021) reported that caponized birds had a 9% increase in bone mineral density compared to intact males. The higher relative femur weights observed in caponized birds, particularly in Treatments 3 and 4, suggest that caponization may contribute to a stronger skeletal frame when nutritional support is optimal. Ojediran *et al*. (2018) found that caponized cockerels had femur weights 12% greater than those of un-caponized birds, indicating improved bone strength.

Bone length differences were observed across treatments, with caponized Noiler and Black Harco chickens generally exhibiting longer tibia and femur bones than their un-caponized counterparts. The longest tibia and femur bones were recorded in caponized Black Harco chickens in Treatment 3 (148.81 mm) and Treatment 1 (100.01 mm), respectively. Chen *et al*. (2020) reported that caponization resulted in a 5% increase in femur length compared to intact males, supporting the notion that caponization delays ossification, allowing for extended bone growth and increased bone mass. Variations in tibia and femur extremity diameters further illustrate the influence of protein sources and hormonal changes on bone structure. The highest tibia top extremity diameter was observed in caponized Black Harco chickens in Treatment 3 (28.31 mm), while the largest bottom extremity diameter was found in Treatment 4 (16.91 mm). These results indicate that protein quality is crucial in enhancing bone structural integrity. Femur extremity diameter (top) was highest in Treatment 1 (24.51 mm), while the bottom extremity diameter was greatest in Treatment 1 (23.21 mm), demonstrating significant dietary effects on skeletal robustness. The midshaft diameters of the tibia and femur, particularly in Treatments 1 and 2, suggest that caponization positively influences bone robustness and structural strength. Cheng *et al*. (2018) found that caponized birds exhibited a 7% increase in midshaft diameter compared to un-caponized birds, aligning with studies indicating that caponization promotes bone thickening and

improved mineral retention. These findings demonstrate that caponization did not notably impact bone growth across all treatments. Instead, its effects varied depending on the protein source. Birds fed GNC-based diets without fishmeal and those receiving cottonseed cake (CSC) displayed increased femur dimensions, suggesting that caponization's impact on bone development depends on protein source composition. Lin *et al*. (2013) reported that caponized cockerels fed diets with high-quality protein sources had a 10% increase in femur length compared to those on lower-quality proteins.

Conclusions

This study highlights significant impact of caponization and dietary protein sources on the skeletal development of Noiler and Black Harco cockerels. Caponization was found to enhance live weight and bone structure, particularly when combined with high-quality protein sources like groundnut seed cake (GNC) mixed with fishmeal. The observed differences in tibia and femur dimensions, extremity diameters, and midshaft diameters underscore the interplay between hormonal regulation and nutrient availability in shaping bone integrity. Furthermore, protein source selection played a crucial role in optimizing bone formation, with specific diets supporting superior mineralization and bone mass accretion in caponized birds. These findings demonstrates that balancing caponization with optimal dietary formulations is essential for producing healthier, more efficient, and economically viable Noiler and Black Harco cockerel stocks.

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