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Morphological and phaneroptic traits of Creole goats reared in an extensive system in the dry forest of Tumbes, Peru

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Abstract. *Temoche VA, Godoy DJ, Trillo FC, Ortiz N, Cruz J. 2024. Morphological and phaneroptic traits of Creole goats reared in an extensive system in the dry forest of Tumbes, Peru. Biodiversitas 25: 4148-4161.* This study aimed to characterize the phaneroptic and morphometric traits of Creole goats in Northwestern Peru. A total of 100 goats were evaluated for 19 phaneroptic and 24 morphometric variables, along with 15 zoometric indices. Descriptive statistics and Principal Component Analysis (PCA) were used to condense body index variables into uncorrelated components, potentially useful in selection programs. The feasibility of PCA was confirmed with the Kaiser-Meyer-Olkin Measure and Bartlett's Test of Sphericity. Phaneroptic results revealed that most goats exhibit plain coats (53%) with mottled and patch patterns (13% each), with 60% showing horns (45% arched and 15% spiraling) and drooping ears (60%). Beards were present in 34% and wattles in 27%. Female teats tended to be divergent (74%), with 33.77% showing supernumerary teats. Morphometric indices indicated predominantly brevilinear, dolichocephalic, and mesoprosopic traits, with a convex linear pelvis. These traits highlight their suitability for meat production, demonstrated by body strength, depth, and width, indicating high potential for producing carcasses of various compactness levels. These findings provide valuable data on the adaptability and morphological diversity of Creole goats, supporting future conservation and breeding efforts.

Keywords: Genetic diversity, phenotypic traits, traditional farming

INTRODUCTION

Since their domestication, goats have been crucial for supporting vulnerable families by providing essential products like food, income, and employment (Silva-Jarquin et al. 2019; Akounda et al. 2023). This role is particularly vital in countries with emerging economies, where goats contribute significantly to food security in rural communities facing challenges such as climate change and economic issues (Aguirre et al. 2021; Ludeña et al. 2021). Therefore, prioritizing their study and characterization is imperative (Maldonado-Jáquez et al. 2023). Additionally, rescuing the productive potential of the Creole goat through the morphometric and phenotypic examination is essential.

Following the conquest, Peru received its first breeding pair of goats from Spanish smallholders in 1556 (Gómez-Urviola et al. 2016). Breeds such as Anglo-Nubian, Alpina, and, to a lesser extent, Toggenburg, were part of the formation of the Creole goat, with the Anglo-Nubian breed being predominant (Arroyo 2007). The goat population in Peru is around 1,038,109, and there are 95,184 goat breeders across the country (MIDAGRI 2022), with herds mainly used for meat or mixed production (Sarria et al. 2014).

Goats in Peru are raised in diverse geographical regions characterized by varied climates, physiographic features, and botanical compositions (Oyolo 2020). These areas include the northern coast's dry forests, the western Andes, and the valleys of the central coast, each utilizing different food resources, from grazing in dry forests to using crop residues and engaging in transhumance (Sarria et al. 2014). In Tumbes, Peru, Creole goats thrive under extensive systems due to their resilience in low-capacity livestock environments (Rodríguez and Álvarez 2005), primarily in dry forests where they feed on temporary forages and leaf litter without disrupting forest diversity (Ortiz et al. 2019). Creole goats exhibit strong adaptability to various environments, owing to their longevity, fertility, maternal instincts, and disease resistance (Whannou et al. 2022). Despite their genetic diversity, which allows for the segregation of favorable genes tailored to smallholder production goals (Gómez-Urviola et al. 2016), genetic improvement programs have reduced in-situ genetic variability through the introduction of exotic breeds and uncontrolled crossbreeding (Aguirre et al. 2021; Corredor et al. 2024).

Morphometric characterization is crucial in classifying animals based on size and shape (Tade et al. 2021), providing insights into productive patterns and suitability for specific zootechnical applications through various body measurements (Rivera 2023). These indices, derived from quantitative data, offer estimations of an animal's structural conformation and functional trends beyond individual measurements alone (Chacón et al. 2011). Visual and morphometric assessments are practical and economically feasible among smallholders compared to molecular marker-assisted selection tools (Ilham et al. 2023). Furthermore, it promotes the conservation of Creole herds and enhances productivity (Getaneh et al. 2022; Akounda et al. 2023). Research on the morphometric and phenotypic characterization of Creole goats in Peru is currently limited. The current study aims to determine morphometric and phaneroptic measurements and estimate body indices to identify the biotype of Creole goats from the dry forest of Tumbes, Peru, as an important genetic resource for local development.

MATERIALS AND METHODS

Study area

The study was conducted in three districts of Tumbes: Canoas de Punta Sal and Casitas in the province of Contralmirante Villar and San Jacinto in the Tumbes region, located in the dry forest of northwest Peru. The Tumbes region covers a total area of 46,669.20 km^2 and is at an elevation of 6 masl. It is characterized by a warm climate with an average temperature of 23°C and humidity of 82% (Peña 2019) (Figure 1).

Most goat farming in the study area is extensive, involving the daily movement of animals in search of food, utilizing only one breeding pen. Breeding occurs continuously, resulting in early reproduction among offspring, which delays their growth and lowers overall production. Planning for production and sales is generally absent, although a few farms adopt intensive methods such as zero grazing (Arroyo 2007). Goats primarily feed on the floristic components of the dry forest, mainly comprising the herbaceous stratum (65%), followed by the shrub (21%) and tree stratum (14%) (Temoche 2019). Trees are utilized for leaf litter, fruits, and inflorescence. Key species consumed include *Neltuma* sp., *Capparis scabrida* Kunth, *Cordia lutea* Lam., *Acacia macracantha* Humb. & Bonpl. ex Willd., *Bougainvillea peruviana* Humb. & Bonpl., *Mimosa albida* Humb. & Bonpl. ex Willd., *Hibiscus phoeniceus* Jacq., *Discletera* sp., *Evolus* sp., and *Desmodium scorpiurus* (Sw.) Desv. ex DC. (Otivo 2015).

Animal sampling

Sampling sites were selected based on geographical representation and goat population density in the Tumbes dry forest region. The study focused on three main localities (i) Casitas; (ii) Canoas de Punta Sal; and (iii) San Jacinto, which collectively account for 48.85%, 26.13%, and 7.82% (MIDAGRI 2022) of the total goat population in the region, respectively. The estimated total goat population in the region is 62,949 goats, which represents 100% of the caprine population in Tumbes. Of this total, approximately 52,122 goats (82.8%) are concentrated in the three main districts under study: Casitas with 30,750 goats, Canoas de Punta Sal with 16,450 goats, and San Jacinto with 4,922 goats.

To determine an adequate sample size, a stratified finite population sample determination formula (Marí et al. 2007) was used based on the 52,122 goats in these three main localities. Parameters for the calculation included a 95% confidence level (Z=1.96), an expected variability proportion (p=0.5, q=0.5), and a 10% margin of error (E=0.10). With these values, the recommended sample size was 96 animals. To ensure representativeness, a total of 100 goats (77 females and 23 males) from 25 herds was selected, proportionally distributed across the districts (Ramzan et al. 2020).

The distribution of evaluated animals was as follows: Canoas de Punta Sal (n=17), San Jacinto (n=25), and Casitas (n=58). Producers were identified and selected with assistance from agricultural agencies in the districts and the regional agriculture office of Tumbes, which provided a roster of goat producers. A maximum of four animals per herd were selected for body measurements to avoid sampling of related animals (Akounda et al. 2023).

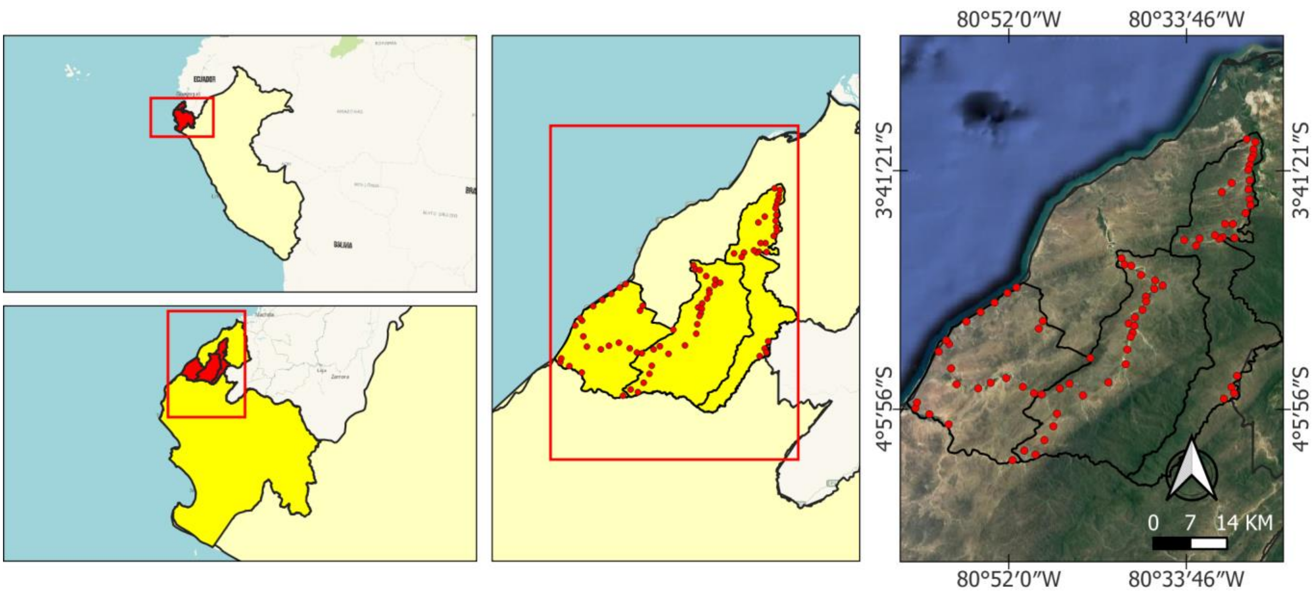

Figure 1. Map of Tumbes, Peru, showing the study area in three districts A. Canoas de Punta Sal; B. Casitas; C. San Jacinto, Tumbes, Peru

To ensure that only adult animals were evaluated, dental chronology was employed to select goats aged 1.5 years and older. Goats were classified as follows: I0≥3 months to 1 year; I1=1 to 1.5 years; I2=1.5 to 2.5 years; I3=2.5 to 3.5 years; and I4>3.5 years (Ilham et al. 2023). Only animals classified as I2, I3, and I4 were included in the evaluation, ensuring the selection of mature goats, both males and females, suitable for adult morphometric and phenotypic characterization.

Phaneroptic variables

Nineteen qualitative external traits (Table 1) were selected and recorded using a standardized chart, facilitating detailed data analysis to identify patterns and variations.

Table 1. Description of phenotypic external traits in goats

Variable	Description	Reference
Frontonasal profile	The shape and characteristics of the head as seen from the front and the side. Straight: The line from the forehead to the nose is straight, without pronounced curves. Concave: The line from the forehead to the nose curves inward. Convex: The line from the forehead to the nose curves outward. Subconcave: It has a softer inward curvature, less pronounced than the full concave shape. Subconvex shows a softer outward curvature, less pronounced than the full convex shape.	Whannou et al. (2022); Ilham et al. (2023); Torres-Hernández et al. (2023); Valverde (2023)
Ear size	The relative size of the ears compared to the goat's head. Large ears: Length between 20-30 cm and width around 15-20 cm in larger breeds. Medium ears: Typically measure between 15-20 cm in length and 10-15 cm in width in medium-sized goats. Small ears: have smaller dimensions, with lengths of approximately 10-15 cm and widths of 5-10 cm in smaller breeds.	Whannou et al. (2022); Valverde (2023)
Ear type	Erect ears: Ears that stand upright or nearly upright on the goat's head without drooping. Horizontal ears: Ears positioned horizontally outward from the sides of the head. Dropped ears: Ears that hang down vertically from the sides of the head.	Whannou et al. (2022); Ilham et al. (2023); Torres-Hernández et al. (2023); Valverde (2023)
Coat pattern	The arrangement and distribution of colors and markings on the goat's fur. Plain or flat: Uniform color without any markings or variations. Mottled or patched: Irregular spots, blotches, or patches of different colors or shades distributed over the coat's base color.	Baenyi et al. (2020); Rakib et al. (2022); Arenas-Báez et al. (2023); Ilham et al. (2023); Maldonado-Jáquez et al. (2023); Torres-Hernández et al. (2023)
Fur color	The overall coloration on the goat's fur or hair.	Rakib et al. (2022); Arenas-Báez et al. (2023); Ilham et al. (2023); Maldonado-Jáquez et al. (2023); Valverde (2023)
Hair size	The length and texture of the goat's hair. Short hair: Hair relatively close to the skin, with a length of less than 2 cm. Medium: Hair that is longer, between 2 and 5 cm. Large hair: Hair that is significantly longer, with a length of more than 5 cm.	León (2022)
Incidence of horn	Indicates whether the goat has horns or is polled	Whannou et al. (2022); Ilham et al. (2023)
Horn form	Spiraling: Horns that twist or spiral along their length. This can vary from a gentle spiral to a tightly wound coil. Arched: Horns that curve gracefully in a smooth arch shape.	Whannou et al. (2022); Torres-Hernández et al. (2023); Valverde (2023)
Incidence of beard	Presence or absence on a beard.	Whannou et al. (2022); Ilham et al. (2023)
Mucosal pigmentation	The pigmentation present on the mucous membranes inside the goat's mouth and around the eyes	Whannou et al. (2022); Torres-Hernández et al. (2023)
Color of mucous	The coloration of the goat's mucous membranes can vary from pale pink to dark pigmented.	Whannou et al. (2022)
Hooves color	The coloration of the goat's hooves	Oyolo (2020.
Type of udder	Bowl: Rounded and concave shape, resembling a bowl. Cylindrical: Elongated and cylindrical shape, with a more uniform diameter from the base to the teats. Funnel: Conical or funnel-like shape, with a wider base that narrows towards the teats.	Amao et al. (2003); Vrdoljak et al. (2020); Lozano et al. (2021); León (2022)
Udder pigmentation	Whether the udder was pigmentation or uniformly colored.	Amao et al. (2003); Torres-Hernández et al. (2023)
Teat type	Normal teats: Typical teat structure found on goats, where each udder half has one teat. Supernumerary teats: Additional teats that exceed the typical number found in goats.	Lozano et al. (2021); Vrdoljak et al. (2020); Whannou et al. (2022)
Teat direction	Divergent: Teats that are spread apart or diverge from each other, pointing in different directions. Parallel: Positioned and aligned with the goat's abdomen, hanging uniformly and straight without tilting to one side or the other	Vrdoljak et al. (2020); Lozano et al. (2021); León (2022)
Teat colored	Whether the teats were pigmentation or uniformly colored.	Amao et al. (2003); Vrdoljak et al. (2020)
Scrotal bipartition	Presence on a divided or partially divided scrotum in bucks.	Aguirre et al. (2021); Tade et al. (2021)
Incidence of wattle	Whether the goat has wattles, which are fleshy appendages typically found hanging from the neck or chin.	Whannou et al. (2022); Torres-Hernández et al. (2023); Valverde (2023)

Morphometric variables and zoometric indices

Morphometric measurements were conducted using standardized tools: a 1.2 m wooden ruler with sliding height bars for elevations and lengths, an inextensible tape for perimeters and lengths, and a hook-type electronic balance accurate to ±0.01 kg for weight measurements. Nineteen morphometric measurements included Head Length (HL), Face Length (FL), Face Width (FW), Chest Width (CW), Thoracic Perimeter (TP), Cross Height (CH), Back Height (BH), Rump Height (RH), Tail Birth Height (TBT), Rump Width (RW), Rump Length (RL), Longitudinal Diameter (LD), Body Depth (BD), Abdominal Perimeter (AP), Dorsal Sternal Diameter (DED), Bicostal Diameter (Dbi), Anterior Shaft Perimeter (SP), Posterior Shaft Perimeter (PSP), and Hock Height (HH). Two additional measurements were evaluated for males: Scrotal Circumference (SC) and Scrotal Length (SL). For females, five additional measurements were recorded: Udder Depth (UD), Udder Length (UL), Teat Between Distance (TBD), Teat Diameter (TD), and Teat Length (TL).

Moreover, 15 zoometric indices were calculated using the morphometric measurements: Body Index (BI), Cephalic Index (CEI), Facial Index (FI), Thoracic Index (TI), Pelvic Index (PI), Proportionality Index (PRI), Metacarpal-Thoracic Index (MET), Metacarpal-Costal Index (MCOS), Posterior Foot Index (PFI), Relative Chest Depth Index (RCD), Transverse Pelvic Index (TPI), Longitudinal Pelvic Index (LPI), Compactness Index (ICOMP), Relative Cannon Thickness Index (RCT), and Cannon Load Index (CLI).

Data analysis

Data were analyzed using R v.4.3.1 software (R Core Team 2023). Phaneroptic characteristics (qualitative variables) were evaluated by estimating frequencies based on sex and location. Morphometric measurements (quantitative variables) were analyzed using descriptive statistics, including mean, median and standard deviation, to assess central tendency and data dispersion. Morphometric indices were compared by sex and district using a one-factor ANOVA, and Pearson's correlation was used to examine linear relationships among variables (Abd-Allah et al. 2019).

Body measurements were analyzed to assess whether Creole goats exhibit a balanced body shape (Figure 2). The formula applied for this evaluation was: BI=(LD/TP)×100; CEI=(FW/HL)×100;FI=(FW/FL)×100; TI=(BDi/DSD)×100; PI=(RW/RL)×100; PRI=(CH/LD)×100; MET=(PS/TP)×100; MCOS=(PS/BDi)×100;PFI=(HH/TBH)×100;RCD=(DSD/CH)×100;TPI=(RW/CH)×100;LPI=(RL/CH)×100;ICOMP=(PV/CH)×100; RCT=(PS/CH)×100;CLI=(PS/PV)×100 (Popoola and Adekanbi 2017).

Principal Component Analysis (PCA) was employed to condense the body index variables into uncorrelated principal components, potentially serving as identifying factors in selection programs. The feasibility of the data before PCA analysis was assessed using the Kaiser-Meyer-Olkin Measure (KMO) and Bartlett's Test of Sphericity. Statistical analyses were performed using SPSS v.16 software (Khargharia et al. 2015).

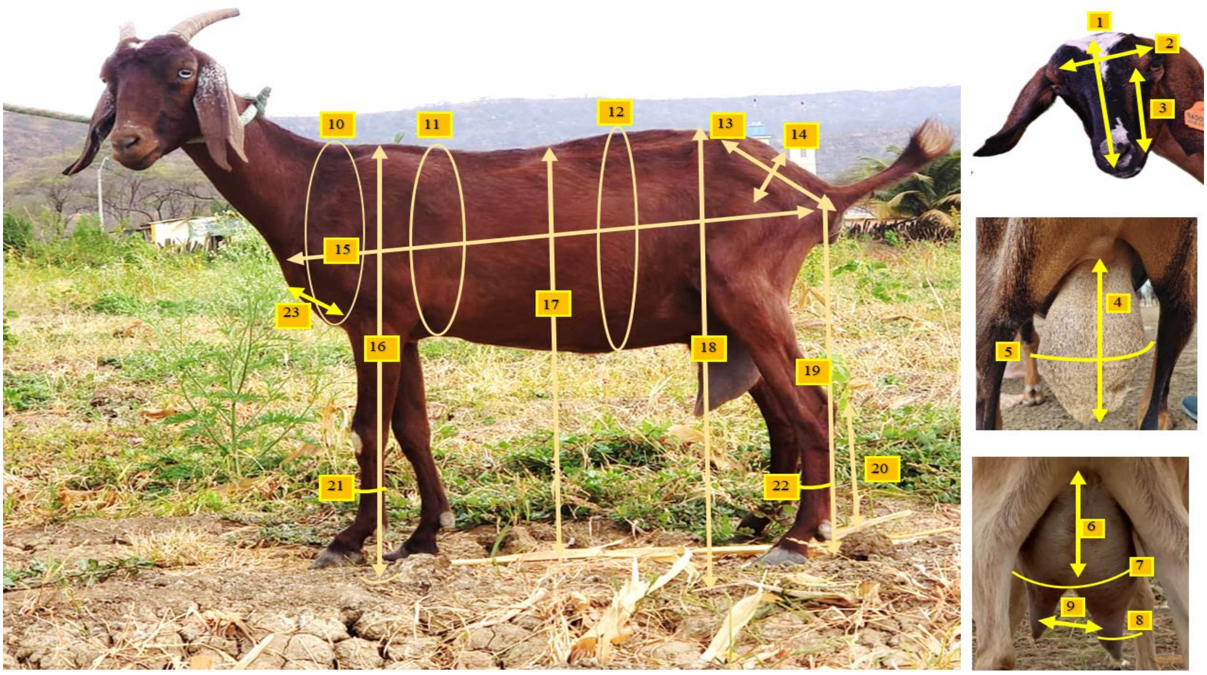

Figure 2. Zoometric measurements of Creole goats from Tumbes, Peru. 1. Head length; 2. Face width; 3. Face length; 4. Scrotal length; 5. Scrotal circumference; 6. Udder length; 7. Udder depth; 9. Teat diameter; 9. Teat between distance; 10. Sternal dorsal diameter; 11. Thoracic perimeter; 12. Abdominal perimeter; 13. Rump length; 14. Rump width; 15. Longitudinal diameter; 16. Cross height; 17. Back height; 18. Rump height; 19. Tail birth height; 20. Hock height; 21. Anterior shaft perimeter; 22. Posterior shaft perimeter; 23. Chest width

RESULTS AND DISCUSSION

Phaneroptic variables

Table 2 presents an analysis of the phenotypic traits of goats from the Tumbes region, emphasizing sex differences. Notably, both male (73.90%) and female (67.50%) goats exhibited a prevalent straight frontonasal profile (Figure 3). Large ear size and dropped ear direction were predominant, observed in 52.20% of males and 64.90% of females, 52.20% of males and 62.30% of females, respectively.

Table 2. Absolute Proportion (AP) and Relative Frequencies (RF, %) of phaneroptic traits according to sex

Variable	Total	Male		Female		p-value
		AP	RF	AP	RF	
Frontonasal profile						
Concave	6	2	8.70	4	5.20	0.033
Convex	9	2	8.70	7	9.10	
Straight	69	17	73.90	52	67.50	
Subconcave	7	2	8.70	7	9.10	
Subconvex	9	0	0.00	7	9.10	
Ear size						
Large	62	12	52.20	50	64.90	0.016
Small	24	5	21.70	19	24.70	
Medium	14	6	26.10	8	10.40	
Ear direction						
Dropped	60	12	52.20	48	62.30	0.312
Erected	20	7	30.40	13	16.90	
Horizontal	20	4	17.40	16	20.80	
Coat pattern						
Plain or flat	53	13	56.50	40	51.90	0.042
Mottled or parched	47	10	43.50	37	48.10	
Fur color						
Bay	3	2	8.70	1	1.30	0.033
White	13	4	17.40	9	11.70	
Brown	9	3	13.00	6	7.80	
Moor	11	3	13.00	8	10.40	
Black	19	2	8.70	17	22.10	
Red	9	3	13.00	6	7.80	
White, black, or Brown/Mottled	13	3	13.00	10	13.00	
White, black, or Brown/Patch	13	1	4.50	12	15.60	
White, black, or Brown/Bezoar	10	2	8.70	8	10.30	
Hair size						
Short	62	14	60.90	48	62.30	0.05
Medium	24	5	21.70	19	24.70	
Large	14	4	17.40	10	13.00	
Incidence of horns						
Absence	40	7	30.40	33	42.90	0.239
Presence	60	16	69.60	44	57.10	
Horn form						
Arched	45	12	52.20	33	42.90	0.066
Spiraling	15	4	17.40	11	14.20	
Incidence of beard						
Absence	66	14	60.90	52	67.50	0.362
Presence	34	9	39.10	25	32.50	
Mucosal pigmentation						
Absence	35	11	47.80	23	29.90	
Presence	65	12	52.20	54	70.10	0.044
Color of mucous						
Yellow	3	1	4.30	2	2.60	0.335
Brown	38	7	30.40	31	40.30	
Black	26	4	17.40	22	28.60	
Pink	33	11	47.80	22	28.60	
Hooves color						
Yellow	3	1	4.30	2	2.60	0.335
Brown	38	7	30.40	31	40.30	
Black	26	4	17.40	22	28.60	
Pink	33	11	47.80	22	28.60	
Incidence of Wattle						
Absence	73	13	56.50	60	77.90	0.042
Presence	27	10	43.50	17	22.10	
Scrotal bipartition						
Absence	6	6	26.10			0.065
Presence	17	17	73.90			

Coat patterns varied significantly (Figure 4), with plain or flat patterns predominant, observed in males (56.50%) and females (51.90%). Horn presence was predominant, observed in males (69.60%) and females (57.10%). Absence of a beard was common in males (60.90%) and females (67.50%). Mucosal pigmentation was more prevalent in females (70.10%) than in males (52.20%). Normal nipple teat types were predominant among females (66.20%), along with a prevalent divergent teat direction (74.00%) (Table 3). Finally, in males, scrotal bipartition predominated with 73.90%.

Morphometric measurements

Table 4 presents the zoometric measurement results of Tumbes goats. Females reached adult body weights of 38.25±7.06 kg and CH of 66.97±6.07 cm, while males showed weights of 37.18±7.40 kg and CH of 70.83±6.26 cm. The evaluated females showed a shallow udder with weak insertion and medium horizontal implantation.

Figure 3. Frontonasal profile of Creole goats from Tumbes, Peru. A. Straight profile; B. Concave profile; C. Convex profile; D. Subconcave profile; E. Sub-convex profile

Figure 4. Diversity of coat colors of Creole goats from Tumbes, Peru

The study highlighted significant gender differences in linear and circumferential measurements, providing insights into various morphological aspects and body conformation. For instance, male goats exhibited a RH of 70.39±7 cm, BD of 36.63±6.18 cm, AP of 93.51±10.52 cm, DBi of 22.65±4.70 cm, and PSP of 7.49±7.17 cm. In contrast, females exhibit an RH of 67.96±6.01 cm, BD of 38.50±7.48 cm, AP of 97.61±12.88 cm, a DBi of 19.92±4 cm, and a PSP of 11.71±2.23 cm. These findings offer a detailed insight into the morphological variations between genders within the studied goat population.

Strong positive correlations (values higher than 0.50) were observed among various morphometric measurements, such as BW, TP, CH, RH, RW, RL, AP, and LD, indicating consistent growth and physical development patterns. Significant negative correlations were found for FL, AP, and BDi.

The highest correlation estimates were between TP and AP, followed by TP and BW, with values of 0.76 and 0.71, respectively. These correlation estimates provide further insights into the complex relationships among measured body dimensions (Table 5).

Table 3. Absolute Proportion (AP) and Relative Frequency (RF) of udder and teat characteristics in goats

Variable	Female		p-value
	AP	RF	
Type of udder			
Bowl	18	23.40	0.037
Cylindrical	43	55.80	
Funnel	16	20.80	
Udder colored			
Yellow	2	2.60	0.037
Brown	31	40.30	0.145
Black	22	28.60	
Pink	22	28.60	
Teat type			
Normal nipple	51	66.20	0.552
Supernumerary nipple	26	33.80	
Teat direction			
Divergent	57	74.00	0.048
Parallel	20	26.00	
Teat color			
Yellow	2	2.60	0.145
Brown	31	40.30	
Black	22	28.60	
Pink	22	28.60	

Table 4. Zoometric measurements of Creole goats from Tumbes, Peru according to sex: Mean, standard deviation and median

Zoometric measurement	Males (n=23)			Females (n=77)			p-value
	Mean[1]	SD	Median	Mean[1]	SD[2]	Median	
Body weight	37.18[a]	7.40	35.56	38.25[a]	7.07	38.40	0.057
Head Length	33.84[a]	3.17	34.20	33.63[a]	2.76	33.65	0.507
Face length	20.87[a]	1.38	20.41	21.20[a]	1.41	20.58	0.045
Face width	16.32[a]	1.38	15.93	16.79[a]	1.19	16.57	0.487
Chest width	20.22[a]	1.39	20.23	19.11[a]	1.09	18.93	0.191
Thoracic perimeter	80.68[a]	7.94	79.30	81.48[a]	6.05	82.30	0.857
Cross height	70.83[a]	6.27	70.10	66.97[b]	6.07	65.50	0.035
Back height	68.13[a]	4.67	68.23	68.79[a]	4.47	69.23	0.392
Rump heigh	70.39[a]	7.00	69.60	67.96[b]	6.01	65.50	0.022
Tail birth height	65.99[a]	4.88	65.23	66.03[a]	4.14	65.44	0.523
Rump length	17.80[a]	1.58	18.10	17.14[a]	2.05	16.70	0.171
Longitudinal diameter	67.63[a]	6.51	68.10	67.02[a]	7.23	67.10	0.753
Body depth	36.63[a]	6.18	35.50	38.50[b]	7.48	38.40	0.042
Abdominal perimeter	93.51[a]	10.52	90.50	97.61[b]	12.88	96.00	0.032
Dorsal sternal diameter	35.90[a]	2.65	36.41	34.72[a]	2.82	35.16	0.048
Bicostal diameter	22.65[a]	4.70	23.40	19.92[b]	4.00	18.30	0.286
Shank perimeter	9.89[a]	1.13	9.57	9.38[a]	0.76	9.41	0.031
Posterior shank perimeter	7.49[a]	7.17	7.56	11.71[b]	2.23	11.06	0.044
Hock Height	30.34[a]	1.83	30.21	31.24[a]	2.44	30.56	0.505
Udder depth				15.42	1.87	15.40	-
Udder length				19.65	2.89	20.11	-
Teat between Distance				11.72	1.44	11.58	-
Teat diameter				5.91	1.47	5.74	-
Teat length				5.52	1.03	5.42	-

Note: [1]letter superscripted a and b in the table means statistically significant differences between the compared groups; SD: Standard Deviation; n: Sample size. The variables Udder depth, Udder length, Teat between Distance, Teat diameter, and Teat length were measured only in females; therefore, no statistical comparison between sexes was performed

Table 5. Estimate correlations among the morphometric measurements, sex, and three districts of Tumbes correlation values above the diagonal, p-values below the diagonal

	HL	FL	FW	BW	CW	TP	CH	BH	RH	TBH	RW	RL	LD	BD	AP	DSD	BDi	SP	PSP	HH
HL		-0.197	-0.037	-0.109	-0.105	-0.102	-0.002	0.106	-0.011	-0.087	-0.058	-0.118	0.095	-0.054	-0.212	0.067	0.279	-0.123	-0.189	-0.047
FL	0.049		0.393	0.120	0.027	0.091	-0.059	-0.084	0.060	-0.002	-0.091	0.153	0.017	0.135	0.117	-0.082	-0.169	0.058	-0.048	0.101
FW	0.714	<0.001		0.127	0.072	0.100	0.009	0.219	-0.023	-0.011	0.052	0.209	0.215	0.173	0.122	0.097	-0.181	-0.072	-0.061	0.154
BW	0.281	0.236	0.210		-0.052	0.705	0.558	0.258	0.622	0.168	0.524	0.622	0.467	0.345	0.687	0.101	0.027	0.217	-0.128	0.132
CW	0.300	0.789	0.476	0.605		-0.151	-0.004	0.039	-0.124	-0.105	-0.162	0.234	-0.092	0.027	-0.022	0.012	-0.016	0.135	0.158	-0.147
TP	0.312	0.368	0.321	<0.001	0.133		0.587	0.235	0.608	0.119	0.693	0.430	0.567	0.232	0.764	0.069	0.043	0.185	-0.135	0.218
CH	0.987	0.562	0.926	<0.001	0.966	<0.001		0.283	0.682	0.126	0.451	0.365	0.481	0.053	0.389	0.116	0.166	0.180	-0.074	0.177
BH	0.292	0.408	0.028	0.010	0.700	0.019	0.004		0.295	0.225	0.353	0.248	0.288	0.234	0.089	-0.007	0.133	-0.049	-0.087	0.255
RH	0.914	0.550	0.822	<0.001	0.218	<0.001	<0.001	0.003		0.267	0.432	0.366	0.491	0.188	0.494	0.100	0.173	0.269	-0.090	0.185
TBH	0.387	0.987	0.912	0.109	0.299	0.240	0.210	0.024	0.007		0.135	0.011	-0.027	0.196	0.091	-0.123	0.242	-0.040	0.197	0.227
RW	0.567	0.369	0.609	<0.001	0.107	<0.001	<0.001	<0.001	<0.001	0.182		0.392	0.504	0.081	0.498	0.122	0.168	0.047	-0.150	0.297
RL	0.241	0.129	0.037	<0.001	0.019	<0.001	<0.001	0.013	<0.001	0.911	<0.001		0.452	0.206	0.410	0.177	0.068	0.237	-0.041	0.143
LD	0.348	0.866	0.032	<0.001	0.364	<0.001	<0.001	0.004	<0.001	0.787	<0.001	<0.001		0.113	0.395	0.013	-0.002	0.166	-0.151	0.136
BD	0.593	0.180	0.085	<0.001	0.787	0.020	0.600	0.019	0.061	0.051	0.421	0.040	0.265		0.355	-0.076	-0.322	0.242	-0.160	0.078
AP	0.034	0.247	0.227	<0.001	0.830	<0.001	<0.001	0.377	<0.001	0.368	<0.001	<0.001	<0.001	<0.001		0.014	-0.182	0.105	-0.046	0.120
DSD	0.508	0.417	0.335	0.317	0.902	0.497	0.250	0.949	0.321	0.224	0.226	0.245	0.900	0.452	0.891		0.184	-0.054	0.125	0.052
BDi	0.005	0.093	0.071	0.792	0.875	0.668	0.098	0.188	0.085	0.015	0.095	0.501	0.983	<0.001	0.070	0.067		-0.103	0.152	-0.019
SP	0.224	0.565	0.475	0.030	0.181	0.065	0.073	0.630	0.007	0.691	0.644	0.018	0.099	0.015	0.298	0.596	0.307		-0.104	-0.082
PSP	0.060	0.636	0.543	0.204	0.117	0.179	0.465	0.390	0.374	0.049	0.135	0.688	0.133	0.111	0.649	0.217	0.132	0.305		-0.102
HH	0.643	0.315	0.125	0.191	0.145	0.029	0.078	0.010	0.066	0.023	0.003	0.155	0.177	0.439	0.236	0.609	0.850	0.417	0.311	

Note: HL: Head Length, FL: Face Length, FW: Face Width, BW: Body Weight, CW: Chest Width, TP: Thoracic Perimeter, CH1: Cross Height, BH: Back Height, RH: Rump Height, TBT: Tail Birth Height, RW: Rump Width, RL: Rump Length, LD: Longitudinal Diameter, BD: Body Depth, AP: Abdominal Perimeter, DED: Dorsal Sternal Diameter, Dbi: Bicostal Diameter, SP: Anterior Shaft Perimeter, PSP: Posterior Shaft Perimeter, And HH: Hock Height

Zoometric indices

Table 6 shows differences in morphometric indices between sexes, focusing on ethnological and productive aspects. However, no statistically significant differences were found according to the provided p-values (all greater than or equal to 0.05). These findings suggest potential trends or observed variations but do not allow for definitive conclusions regarding group differences. The analysis of morphometric indices in goats from three distinct zones (Casitas, San Jacinto, and Canoas) revealed significant differences in ethnological and productive indices (Table 7). For instance, CEI showed higher values in Casitas (51.47) compared to San Jacinto (46.15) and Canoas (49.99), with these differences being statistically significant ($p<0.05$). Similarly, FI varied significantly across zones, with higher values in Casitas (80.63), contrasting with San Jacinto (77.98) and Canoas (75.74).

Regarding productive indices, MCOS exhibited notable variability, being highest in Canoas (56.23), followed by Casitas (51.48), and significantly lower in San Jacinto (34.73). These differences were highly significant based on p-values ($p < 0.01$). These findings underscore the importance of considering geographic variability in morphometric evaluations of goats, particularly for genetic selection and management purposes.

Table 8 presents PCA performed on the zoometric indices, revealing significant patterns of morphometric variability in the study areas. The data show that the first seven principal components collectively explain 85.92% of the total variability in the indices. Notably, PC1 (eigenvalue=3.172, explaining 21.15% variance) emerged as the most influential, followed by PC2 (eigenvalue=2.484, explaining 16.56% variance) and PC3 (eigenvalue=1.894, explaining 12.63% variance), underscoring their pivotal role in factor structure.

Each zoometric index shows high communalities (>0.75), indicating that most index variances were well-represented by the extracted principal components. The KMO measure of 0.739 indicates adequate sampling adequacy for PCA, confirming that the correlations between the indices are sufficiently strong to justify the analysis. Additionally, Bartlett's test of sphericity yields a significant result ($p < 0.001$), validating the presence of significant correlations among the indices.

In Figure 5, the key observations indicate that ICOMP, TPI, and LPI strongly associate with Dim1, suggesting that these indices are crucial for explaining the variability in this dimension. RCT, MET, and CLI are more influenced by Dim2, indicating their importance in this second dimension. Regarding district patterns, San Jacinto has greater variability, especially in Dim1, which could indicate significant differences in morphometric indices. Canoas de Punta Sal and Casitas have more concentrated patterns, indicating less variability in the indices within these districts than in San Jacinto.

Table 6. Analysis of morphometric indices in goats by sex: Averages, coefficient of determination (R^2), *p-value,* and Coefficient of Variation (CV)

Indexes	Sex[1]		R^2	*p-value*	CV
	Male	Female			
Ethnological interests					
BI	82.76[a]	82.73[b]	0.00	0.99	11.37
CEI	49.38[a]	50.01[b]	0.04	0.66	8.75
FI	78.88[a]	79.20[a]	0.02	0.84	12.98
TI	62.42[a]	58.11[a]	0.14	0.18	4.75
PI	90.77[a]	91.01[b]	0.01	0.93	8.96
PRI	103.05[a]	101.4[a]	0.06	0.58	9.08
Productive interest					
MET	11.53[a]	11.79[a]	0.08	0.44	9.07
MCOS	44.98[a]	48.83[a]	0.15	0.13	4.77
PFI	48.05[a]	46.93[a]	0.11	0.28	11.72
RCD	50.48[a]	52.30[a]	0.12	0.24	8.63
TPI	22.69[a]	23.19[a]	0.09	0.39	10.32
LPI	25.06[a]	25.41[b]	0.05	0.65	8.70
ICOMP	56.77[a]	55.74[b]	0.05	0.65	6.27
RCT	13.57[a]	14.21[a]	0.16	0.12	8.75
CLI	24.28[a]	26.10[a]	0.15	0.13	5.43

Note: [1]different letters between columns indicate ($p<0.05$), BI: Body Index, CEI: Cephalic Index, FI: Facial Index, TI: Thoracic Index, PI: Pelvic Index, PRI: Proportionality Index, MET: Metacarpal Thoracic Index, MCOS: Metacarpal Costal Index, PFI: Posterior Foot Index, RCD: Relative Chest Depth Index, TPI: Transverse Pelvic Index, LPI: Longitudinal Pelvic Index, ICOMP: Compactness Index, RCT: Relative Cannon Thickness Index, CLI: Cannon Load Index

Table 7. Analysis of morphometric indices in goats by zones: Averages, coefficient of determination (R^2), *p-value,* and coefficient of variation

Indexes	District			R^2	p-value	CV
	Casitas	San Jacinto	Canoas			
Ethnological interests						
BI	83.91[a]	82.26[a]	79.44[a]	0.23	0.08	11.37
CEI	51.47[b]	46.15[ab]	49.99[a]	0.39	0.00	8.75
FI	80.63[b]	77.98[ab]	75.74[a]	0.31	0.01	12.98
TI	52.67[a]	77.63[b]	52.76[a]	0.88	0.00	12.11
PI	88.86[a]	92.98[a]	95.16[a]	0.26	0.04	8.96
PRI	99.57[a]	104.10[a]	105.73[a]	0.23	0.06	9.08
Productive interest						
MET	11.70[a]	11.79[a]	11.81[a]	0.04	0.93	9.07
MCOS	51.48[b]	34.73[a]	56.23[c]	0.79	0.00	4.77
PFI	48.87[b]	45.41[a]	44.52[a]	0.45	0.00	11.72
RCD	53.08[b]	52.13[b]	47.85[a]	0.32	0.01	8.63
TPI	23.46[b]	22.97[ab]	22.01[a]	0.24	0.06	10.32
LPI	26.41[b]	24.49[a]	22.96[a]	0.46	0.00	8.70
ICOMP	57.37[b]	52.95[a]	55.44[a]	0.21	0.11	6.27
RCT	14.22[b]	13.79[a]	14.06[a]	0.11	0.54	8.75
CLI	25.40[b]	26.41[a]	25.99[a]	0.09	0.66	5.43

Note: abc: Different letters between columns indicate ($p<0.05$); BI: Body Index; CEI: Cephalic Index; FI: Facial Index; TI: Thoracic Index; PI: Pelvic Index; PRI: Proportionality Index; MET: Metacarpal Thoracic Index; MCOS: Metacarpal Costal Index; PFI: Posterior Foot Index; RCD: Relative Chest Depth Index; TPI: Transverse Pelvic Index; LPI: Longitudinal Pelvic Index; ICOMP: Compactness Index; RCT: Relative Cannon Thickness Index; CLI: Cannon Load Index

Table 8. Principal component matrix with explained variance, Kaiser-Meyer-Olkin measure (*KMO*) of sampling adequacy, and communalities of zoometric indices in the study areas

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7	Communality
Body index	0.085	0.040	0.496	-0.586	-0.929	-0.265	-0.115	0.929
Cephalic index	0.030	0.295	-0.201	-0.390	0.445	0.670	0.195	0.765
Proportionality index	-0.111	-0.464	-0.432	0.253	0.870	0.102	0.161	0.933
Facial index	-0.069	-0.084	0.277	-0.372	0.706	0.861	0.041	0.757
Thoracic index	-0.570	0.849	0.058	-0.154	-0.526	0.412	0.331	0.932
Pelvic index	-0.135	-0.392	0.310	0.826	0.166	0.227	0.264	0.921
Metacarpal thoracic index	0.840	0.012	-0.169	-0.160	-0.122	0.042	0.222	0.880
Metacarpal costal index	0.790	0.970	-0.080	-0.139	0.092	0.036	0.014	0.829
Posterior foot index	0.010	-0.189	0.043	0.154	-0.020	0.539	-0.871	0.900
Relative chest depth index	0.582	0.354	0.746	0.471	0.263	-0.275	-0.169	0.861
Transverse pelvic index	-0.024	0.592	0.859	0.489	0.028	0.273	0.115	0.933
Longitudinal pelvic index	-0.117	0.723	-0.280	-0.921	-0.130	0.173	-0.301	0.785
Compactness index	0.849	0.781	-0.170	0.107	0.164	-0.175	0.103	0.835
Relative cannon thickness index	0.431	0.425	0.532	0.112	-0.141	0.176	0.163	0.961
Cannon load index	0.939	-0.307	0.126	-0.045	-0.224	0.247	0.020	0.902
Eigenvalue	3.172	2.484	1.894	1.640	1.501	1.190	1.001	
Variance percent (%)	21.15	16.56	12.63	10.93	10.01	7.94	6.70	
Accumulated variance (%)	21.15	37.70	50.33	61.27	71.28	79.21	85.92	
Kaiser-Meyer-Olkin *(*KMO*)*	0.739							
Prueba de esfericidad de Bartlett	1395.014							
g.l.	105							
Sig.	0.001							

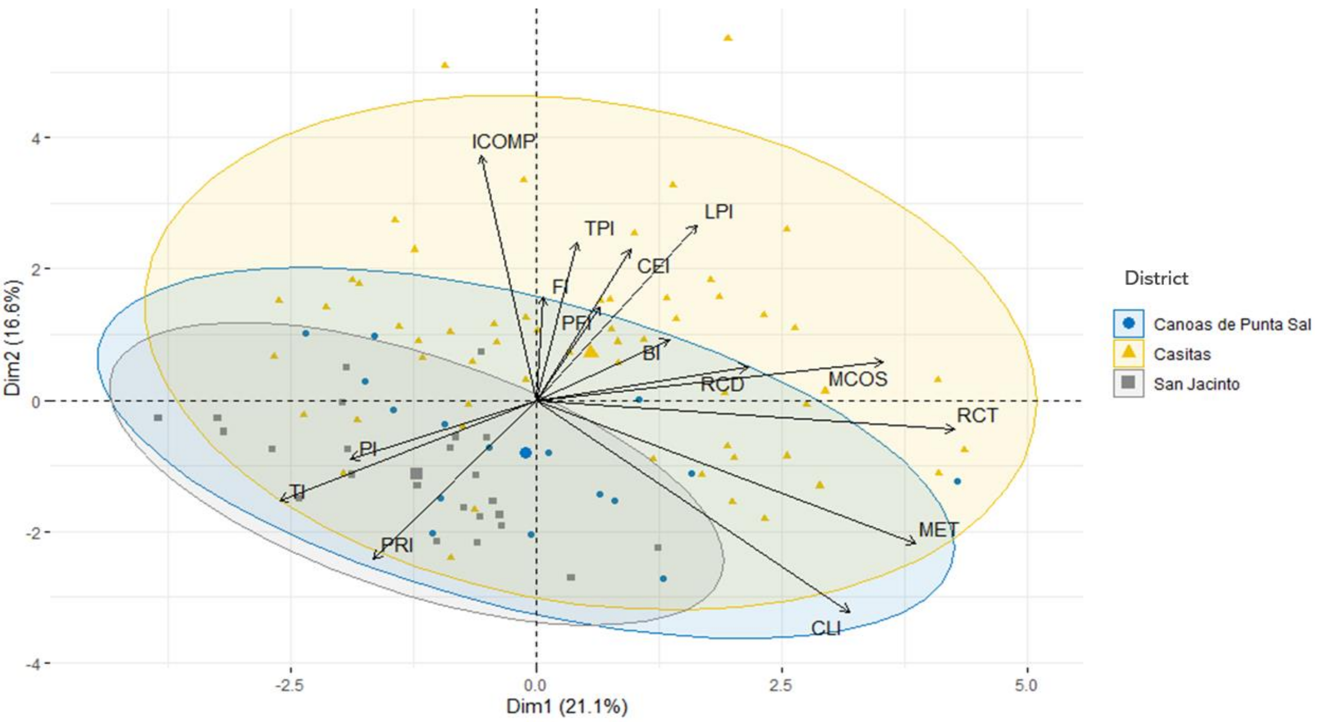

Figure 5. Principal Component Analysis (PCA) of morphometric indices of goats in the three districts studied in Tumbes, Peru, showing the grouping and morphometric variability between Casitas, Canoas de Punta Sal, and San Jacinto. BI: Body Index; CEI: Cephalic Index; FI: Facial Index; TI: Thoracic Index; PI: Pelvic Index; PRI: Proportionality Index; MET: Metacarpal Thoracic Index; MCOS: Metacarpal Costal Index; PFI: Posterior Foot Index; RCD: Relative Chest Depth Index; TPI: Transverse Pelvic Index; LPI: Longitudinal Pelvic Index; ICOMP: Compactness Index; RCT: Relative Cannon Thickness Index; CLI: Cannon Load Index

Discussion

Phaneroptic variables

The present study identified goats from Tumbes, Peru, with straight (69%), concave (6%), convex (9%), subconcave (7%), and subconvex (9%) profiles. Similar reports were found with high percentages of straight profiles (Vrdoljak et al. 2020; Aguirre et al. 2021; Rivera 2023). In contrast, goats from Lima, Peru, and Manabí, Ecuador, exhibited convex frontonasal profile in 62,2 % and 72.8 % of the sampled animals, respectively (Oyolo 2020; Zambrano 2021). Some studies state that frontonasal profile characteristics in goats vary among breeds; for example, dual-purpose breeds such as Anglonubian tend to have convex profiles, whereas breeds such as Boer and Saanen have straight profiles (Arroyo 2007; Gómez-Urviola et al. 2016). These findings suggest that frontonasal profile features might be useful phenotypic indicators for differentiating goat breeds or biotypes (Whannou et al. 2022)

The most sampled goats in Tumbes had large and wide ears, with only 24% having small and thin ears. Similar results were observed in Lima and Manabí, where 62% of the evaluated animals had large and drooping ears (Oyolo 2020; Valverde 2023). Additionally, Creole goats exhibited multicolored short hair coats, pigmented mucous membranes, and, in some cases, a beard and rarely a wattle. These traits describe Creole goats resulting from extensive crossbreeding among breeds such as Anglonubian, Boer, and Murciana, with tendencies toward meat production, dual purpose, and milk production, as indicated by studies conducted by Chacón et al. (2011); Oyolo (2020); León (2022); and Valverde (2023). The evaluated female goats displayed a shallow udder with weak attachment and horizontal positioning, classified as having medium conformation. Among them, 55.8% had a cylindrical udder, 23.4% had a bowl-shaped udder, and 20.8% had a funnel-shaped udder. These findings contrast with those of Lozano et al. (2021), who reported that 42.5% of does exhibit cylindrical udders, with only 19.2% displaying bowl-shaped udders. Vrdoljak et al. (2020) noted that cylindrical udders are associated with higher milk yields and improved udder health due to favorable teat positioning, which can lower the risk of mastitis. This suggests that the prevalence of cylindrical udders in our study could be beneficial for milk production and udder health. However, these goats demonstrate low milk production potential and exhibit extensive crossbreeding with meat breeds. Unlike Beetal goats, which are selectively bred for udder size and placement to enhance milk yield, these goats lack targeted breeding for dairy traits (Ramzan et al. 2020). In Bucks, only 6% exhibit scrotal bipartition, contrasting with the findings of Junior et al. (2011), who found 50% of males with scrotal bipartition.

Morphometric and zoometric indices

The research shows that female goats from Tumbes Region reached average adult weights of 38.25±7.06 kg and cross heights of 66.97±6.07 cm. Furthermore, male goats registered weights of 37.18±7.40 kg and heights of 70.83±6.26 cm, demonstrating with these characteristics that there is a strong influence of large breeds with characteristics for meat production.

Conversely, several studies reported significant differences in weight between females and males (Nunes et al. 2020; Oyolo 2020), always registering a higher weight in males (Traoré et al. 2008; Silva-Jarquin et al. 2019; Aguirre et al. 2021; León 2022; Akounda et al. 2023) These differences can be due to several factors, such as the physiological and nutritional state of the goat, given that the research was cross-sectional and the sampling coincided with the mating season when males have a marked weight loss due to their competitive and reproductive nature. Similarly, both weight and body measurements are influenced by genetic factors, apart from the food consumed, the management of breeding, and the environment (Lozano et al. 2021; Whannou et al. 2022; Ilham et al. 2023).

However, significant differences were found in CH, RH, PSP, BD, and AP, which may be attributed to a pronounced hybridity among Tumbes goats. Similar findings have been reported, where male goats tend to have higher CH, RH, and PSP indices than females, including FL and FW (Dea et al. 2019; Getaneh et al. 2022; Akounda et al. 2023; Valverde 2023).

AP positively correlated with TP, indicating a harmonious morphostructural model characterized by compact amplitude and depth. Conversely, a high negative correlation between AP and HL may suggest minimal fixation in the morphotype of the Tumbes Creole goat. However, in the case of AP, there is a high incidence due to the animal's body condition. Data from Tade et al. (2021), León (2022), and Akounda et al. (2023) demonstrate a wide body diversity with a positive correlation below 12.5%, indicating a lack of specific morphotypes. They also observed that amplitude and height measurements positively correlated with weight and other zoometric measures. The ethnological interest indices suggest that Tumbes goat cattle had characteristics of brevilinear animals (Abarca-Vargas et al. 2020; Oyolo 2020), implying that animals with square or rectangular appearances suitable for butchering determine variations in the thoracic section.

It should be noted that BI and TI values are sometimes inversely proportional, as stated by Abarca-Vargas et al. (2020). Additionally, the data showing CEI (49.38) and FI (78.88) in males and CEI (50.01) and FI (79.20) in females indicate the presence of dolichocephalic and mesoprosopian goats, characterized by rectangular and compact heads. Cephalic and facial variables are crucial for breed description as they are less influenced by environmental and management factors (Rodero et al. 2015; Silva-Jarquin et al. 2019). Finally, the PI reflects rump structure related to body width and pelvic length (Silva-Jarquín et al. 2019). The IPE value of 90.9 suggests a convex linear appearance with a wide, compact, and robust pelvis, showing a clear predominance of length about width, characteristics typical of meat animals widely related to the Boer breed (Lozada-García et al. 2015; Rodero et al. 2015).

Productive and functional interest indices such as the PRI, MET, and MCOS show goats with strong limbs and bones, indicating good strength in the extremities concerning body mass (Abarca-Vargas et al. 2020). PFI shows animals with ideal aplomb, low heels, and strong trotters (Rodero et al. 2015). The ICOMP, RCT, and CLI indicate the relationship between length, depth, and width, suggesting animals with adequate strength and depth are indicators of the potential to produce more or less compact carcasses.

PCA suggests various morphometric characteristics among the sampled districts, identifying seven components explaining a cumulative variability of 85.91%. This contrasts with the findings of Akounda et al. 2023, and Ilham et al. 2023, who identified well-defined goat herds with only two components, explaining 77.26% and 85.4%, respectively. Additionally, PCA using the linear scoring system and correlation with zoometric indices has predictive potential for identifying the productive aptitude of goats in the study areas (Álvarez et al. 2020). Observed variability suggests a gene flow influenced by transhumance activity and livestock breeders' preference for animals with specialized breed characteristics, promoting uncontrolled crossbreeding (Tade et al. 2021). Crossbreeding is a reason for gene introgression, driven by producer preferences and market demand for meat or milk products.

The morphometric indices of Creole goats across the study area districts show homogeneity, primarily in indices related to racial characteristics. In San Jacinto, indices such as PI, TI, and PRI are prominent, indicating goats with meat-producing aptitude (Getaneh et al. 2022; Oyolo 2022). These authors explain that PI, TI, and PRI provide racial information about Creole goats and can indicate their productive aptitude. A similar pattern is observed in the Canoas de Punta Sal district, where the BI index is included. However, Casitas shows considerable variability, especially in productivity-related indices, suggesting less precise selection criteria for Creole goats. These morphostructural weaknesses may be due to the lack of a defined racial standard for goats, as indicated by Oyolo (2022).

The phenotypic variability among Canoas de Punta Sal, Casitas, and San Jacinto districts in morphometric and phenotypic variables may be influenced by environmental factors in goat farming areas (Singh et al. 2022). Coat color has been reported to affect body weight and other productive adaptability factors due to its impact on heat dissipation and radiation levels in grazing areas (Baenyi et al. 2020). Additionally, the morphological characteristics equip Creole goats with resilience to climatological challenges such as droughts or heavy precipitation (Nair et al. 2021), as well as adaptation to diets based on herbaceous, shrubby, and native forest species from Tumbes dry forest (Otivo 2015). Another aspect to consider as a cause of this variability is the criteria and preferences of the producer for selecting goats within their production system. Nose shape, body length, udder size, ear size, and body color have been reported as the most preferred selection traits, evidencing the adaptation of subjective selection criteria rather than objective ones, thus leading to the production of animals with certain morphological attributes along with certain improvements in meat and milk production (Ramzan et al. 2020). Finally, uncontrolled mating leads to the mating of related animals, which in turn can cause loss of fitness and reproductive traits, increasing variability within the same livestock herd (Tilahum et al. 2023)

In conclusion the phaneroptic analysis reveals moderately variable goat herds in Tumbes' dry forest, characterized by pronounced sexual dimorphism and a strong tendency towards crossbreeding with meat or dual-purpose breeds. These goats typically exhibit polychrome coats of short hair, pigmented mucous membranes, and minimal presence of beards and wattles. Ethnological and productive-functional interest indices highlight significant variability among these goats. They are characterized as brevilinear with dolichocephalic and mesoprosopic features, coupled with a convex linear pelvis. These traits signify a robust aptitude for butchering, underscored by their substantial body strength, depth, and width. These characteristics collectively indicate a high potential for producing carcasses of varying compactness.

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