



Morphological characterization of udder and teat traits in Alpine, Saanen, Toggenburg, and crossbred dairy goats in Kenya

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Abstract

Udder and teat morphological characteristics critically influence dairy goat productivity, yet data on Kenyan breeds remain scarce. This study characterized udder and teat traits, a key productivity determinant, in four major dairy goat breeds, Alpine, Saanen, Toggenburg, crossbreeds, across Kenya's production systems. A cross-sectional study assessing 181 lactating does from 56 farms in rural, institutional, and urban settings. Udder symmetry, shape, suspension, depth, teat length, placement, shape, end shape, and separation were evaluated per standardized protocols. Data were analyzed using descriptive statistics, Fisher's Exact test with Cramér's V, and correlation tests in R. Alpines (41%) exhibited the longest teats (5.2 ± 2.0 cm) and highest prevalence of udder asymmetry (48%) among all the studied breeds. Toggenburgs had the deepest udders (11.2 ± 2.9 cm); udder depth refers to the distance measured from the udder floor to the hock joint, and most attached suspensions (45%). Globular (48%) and pear-shaped (40%) udders predominated, with crossbreeds showing the highest prevalence of globular udders (55%). Udder suspension significantly influenced depth ($p = 0.0058$), with loose-suspended udders shallower (8.53 ± 4.09 cm) than attached types (11.7 ± 2.57 cm). Teat length weakly correlated with udder depth ($\rho = -0.19$, $p = 0.01$). Key trait interdependencies emerged: symmetrical udders linked to globular shapes ($p = 0.008$); severe teat separation associated with oblique placement ($p < 0.001$); and teat shape influenced teat-end morphology ($p = 0.013$). Breed-specific udder morphology patterns exist in Kenyan dairy goats, with significant inter-trait relationships. Alpine's high asymmetry and Toggenburg's superior udder attachment highlight breeding targets. Integrating udder suspension, symmetry, and teat placement into future dairy goat selection programs could enhance milking efficiency and management.

Key words: Dairy goats; Kenya dairy goats; Phenotypic variation; Udder and teat characteristics

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Introduction

Dairy goat farming plays a pivotal role in enhancing food security, nutrition, and economic resilience for smallholder farmers in Kenya, particularly in the face of climate change and land scarcity (Kagucia *et al.*, 2020; Kamidi *et al.*, 2022; Njue *et al.*, 2023). The exotic dairy goat breeds (Toggenburg, German Alpines, British Alpine, Saanen and the Anglo-Nubian) were introduced in Kenya Highlands in the Mid-1990s and have been used extensively to upgrade the indigenous goats through crossbreeding to improve productivity (Ojango *et al.*, 2010; Peacock *et al.*, 2011; Waineina *et al.*, 2021). Central Kenya counties in which these exotic breeds were introduced include; Meru, Embu, Nyeri, Kirinyaga, and Murang'a counties (Kiura *et al.*, 2020). These counties account for approximately 80% of the national dairy goat population due to the continuous breeding and expansion of dairy goat farming (Mbindyo *et al.*, 2018). Dairy goat farming contributes 15.2% of total livestock income and 4.8% of overall household income, enhancing nutrition and providing a reliable income source (Ogola *et al.*, 2010; Mutunga *et al.*, 2023). Dairy goat projects have empowered smallholder farmers, especially women, by offering accessible livestock that require less land and capital, and by supporting community-based breeding and training initiatives (Ahuya *et al.*, 2002; Ojango *et al.*, 2010).

As Kenya's population rapidly increases, projected to reach 96 million by 2050 (World Bank, 2016; UNFPA, 2024), the demand for nutrient-dense animal protein, including goat milk, is escalating (FAO, 2017). Goats are considered a low-hanging fruit for poverty alleviation, especially because they are less capital-intensive, have a faster reproductive cycle and can be reared even by vulnerable groups in the community. Goat milk is renowned for its digestibility, hypoallergenic properties, and nutritional richness (Szymanowska *et al.*, 2010; Pal *et al.*, 2017; Park, 2017; Qin *et al.*, 2021; Al Kaisy *et al.*, 2023). Dairy goats and their crosses are considered "climate-smart" livestock due to their heat tolerance, lower methane emissions, and adaptability to diverse agro-ecological zones (Joy *et al.*, 2020; Jesang, 2022).

The udder is central to dairy goat milk productivity (Vrdoljak *et al.*, 2020). Morphological characteristics of the udder and teat, which include traits such as size, shape, symmetry, texture, suspension, and teat orientation, directly impact milking efficiency, thus volume of milk produced, machine compatibility, and kid suckling behaviour (Ozoje, 2002; Pajor *et al.*, 2014; Margatho *et al.*, 2020; Makau, 2017; Gazzola *et al.*, 2021; Gupta *et al.*, 2022). These characteristics show considerable variation both across and within breeds (Margatho *et al.*, 2020; Ahlem *et al.*, 2023; Yao *et al.*, 2025). The desirable under shape and teat configurations which correlate with optimal milk yield and ease of handling include: globular or bowl-shaped and cylindrical teats (Montaldo and Martínez-Lozano, 1993; Margatho *et al.*, 2020; Vrdoljak *et al.*, 2020), while pendulous or asymmetrical udders may negatively impact udder health and milk yield (Margatho *et al.*, 2020; Gupta *et al.*, 2022; de Cremoux *et al.*, 2024).

Despite their importance, udder traits in goats remain understudied globally (Szymanowska *et al.*, 2010). However, morphological heterogeneity in udders and teats in some goat breeds has been documented, for example, the Portuguese Serrana breed has a globular-shaped udder while the West African Dwarf possesses a cylindrical-shaped udder with funnel-shaped teats (Montaldo and Martínez-Lozano, 1993; Amao *et al.*, 2003; Margatho *et al.*, 2020; Gupta *et al.*, 2022). This notwithstanding, there is limited data on udder and teat conformation specific to Kenya's unique dairy goat populations, which are predominantly crossbred and managed under small-scale systems (Ojango *et al.*, 2010; Peacock *et al.*, 2011; Shivairo, 2014; Waineina *et al.*, 2021). Breed improvement programs in Kenya (e.g., FARM-Africa's crossbreeding initiatives) have prioritized milk yield (Ojango *et al.*, 2010; Peacock *et al.*, 2011) but may inadvertently overlook udder and teat conformation traits critical for long-term sustainability (Vrdoljak *et al.*, 2020).

Given the rapid expansion of dairy goat enterprises in Kenya and the critical role of udder morphology in milking efficiency, susceptibility to mastitis, and long-term productivity, this study aimed to characterize the udder and teat

morphology of dairy goats across major Kenyan breeds. By establishing baseline data on these characteristics, this research addressed a critical knowledge gap while providing actionable insights for breed selection, management protocols, and genetic improvement programs tailored to Kenya's dairy goat sector.

Materials and methods

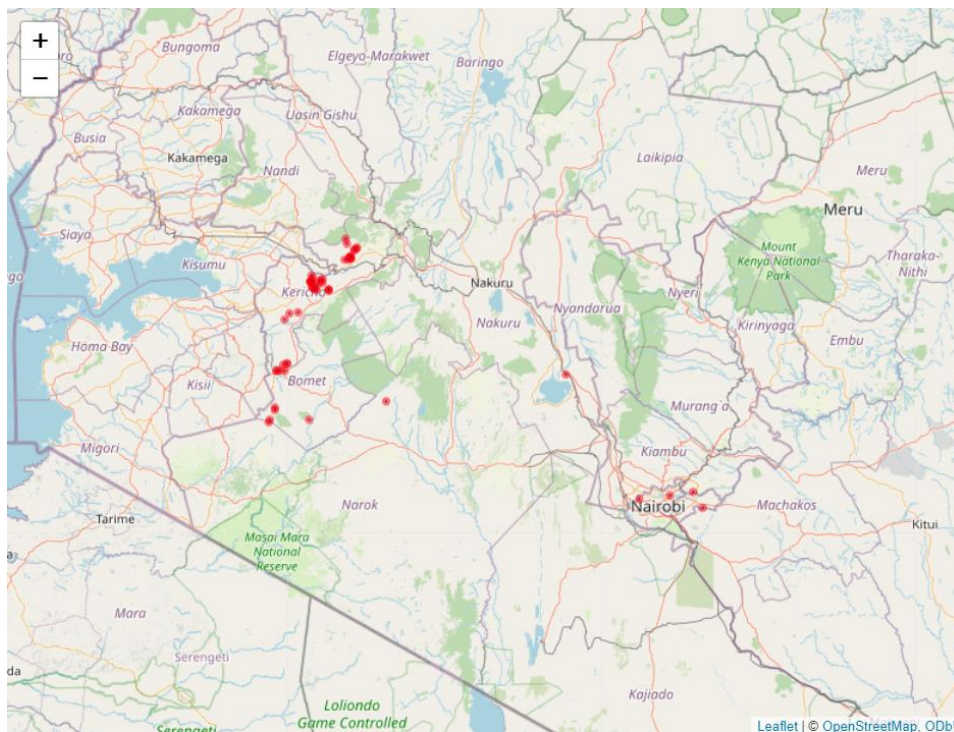
Study Area(s)

A cross-sectional study was conducted across diverse dairy goat farming systems in Kenya, including rural (Kericho, Bomet, Narok), institutional (KALRO Naivasha), and urban (Kiambu, Nairobi) settings to capture environmental and management variability

(Figure 1). The study areas represent distinct agro-ecological zones: Kericho, Bomet, and Narok are humid highlands (1,200–1,800 mm rainfall; 15–25°C; 70–85% humidity) favorable for dairy goats; KALRO Naivasha is semi-arid (600–800 mm; 18–28°C; 50–70% humidity) with moderate stress; while Kiambu and Nairobi are sub-humid (900–1,100 mm; 16–27°C; 60–80% humidity) with variable microclimates. Production systems varied accordingly: rural farms used free-range grazing with minimal inputs; institutional farms employed controlled conditions with standardized management; and peri-urban and urban systems featured limited to no grazing with higher inputs.

Figure 1

The study area showing the geographic distribution of the data points, generated using the R programming language (Team, 2020) and the 'leaflet' package (Cheng, 2021). The red represents households visited during the study



Study design

A cross-sectional design was employed to characterize udder and teat morphology across major Kenyan dairy goat breeds and production systems.

Sample size and selection of animals

A total of 181 lactating does from 56 farms were enrolled. This number was arrived at as this was part of a larger study.

Inclusion criteria: clinically healthy, mid-lactation

(>3 weeks post-kidding), and belonging to Saanen, Alpine, Toggenburg, or crossbred breeds.

Exclusion criteria: indigenous/non-descript goats and does in early or late lactation.

Study animals

Animal biodata was collected via structured questionnaires using Open Data Kit (ODK). Recorded parameters included age, parity, lactation status, and milk yield. The term “cross” was used for does with crossbreeding history or phenotypic expression of multiple breeds. Due to difficulty identifying specific Alpine variants, the genotype “Alpine” was used to include all other variants. Additionally, in each doe, measurements of the heart girth in centimetres (cm) were done using a standardized bovine/porcine weight tape (Medilink Vet Suppliers, Nairobi). Heart girth measurement was used to estimate body weight using the equation by Almazan and Cabaral-Lasaca (2022): $BW (kg) = -53.061 + 1.120 \times HG (cm)$. Direct milk yield data were not reliably available for all 181 does in this study and were therefore excluded from analysis. This limits our ability to correlate morphological traits with actual milk output.

Udder and teat evaluation/assessment

Udder and teat morphology assessments were performed by a single trained investigator pre-milking: Five different udder morphological traits were evaluated: First, udder symmetry was categorized as symmetrical, defined as having balanced left and right halves; moderate asymmetry, indicating a slight deviation; or severe asymmetry, characterized by a marked imbalance. Second, udder shape was classified as globular (rounded and spherical), pear-shaped (wider at the base, tapering toward the teats), or cylindrical (uniform width). Third, udder suspension was categorized as attached, intermediate, or loose, corresponding to the standard classifications of tightly/firmly attached, intermediate, and pendulous, respectively. Fourth, the udder depth, measured as the distance from the most ventral udder floor to the hock joint in centimetres using a tape measure, was recorded. Lastly, teat separation, corresponding to the angle made between the teats at the udder cleft i.e. the smaller the angle the slighter the separation, was evaluated and classified as slight, moderate, or severe, as described by Margatho *et al.* (2020).

Teat characteristics investigated included teat length (measured from the base to the tip in centimeters), teat placement (classified as vertical or oblique) (James *et al.*, 2009), teat shape (described as funnel shape, characterized by a narrow base widening toward the tip; cylindrical, with uniform width; or bottle-shaped, with a wider base tapering to the tip) (Vrdoljak *et al.*, 2020), and teat-end morphology (referred to as pointed, indicating a sharp tip, or blunt, indicating a rounded tip) (Amao *et al.*, 2003). Abnormalities like supernumerary teats were also recorded.

Ethical approval

Ethical approval for this study was obtained from the University of Nairobi Faculty of Veterinary Medicine Biosafety, Animal Use and Ethics Committee (REF: FVM BAUEC/2023/529). Informed consent was obtained from all participating farmers prior to data collection.

Statistical analysis

Data were cleaned using Microsoft Excel 2021 and analysed in R statistical software version 4.4.1 (Team, 2020) using base R functions and the following packages: ‘stats’ (for Fisher’s Exact Test, correlation), ‘dplyr’ (for data manipulation and descriptive statistics), ‘ggplot2’ (for data visualization), and ‘car’ (for ANOVA and post hoc tests). Descriptive statistics (frequencies for categorical traits; mean \pm SD for continuous variables) characterized morphological variation. Associations between breed/age/parity/lactation stage and udder/teat traits were quantified using Fisher’s Exact Test with Cramér’s V effect size, while Pearson/Spearman correlation assessed relationships among udder depth, teat length, and heart girth. Body weight was estimated from heart girth using the equation by Almazan and Cabaral-Lasaca (2022): $BW (kg) = -53.061 + 1.120 \times HG (cm)$. Statistical significance was accepted at $p < 0.05$.

Results

Age, body weight and body condition scores of the does and breed distribution

The average body weight was 32.5 ± 6.6 kg and ranged from 17.5 kgs to 53.3 kgs for all dairy goats in this study (Table 1). Alpine weighed comparably higher, while Saanens had the lowest average body weight (Figure 2). The mean body

condition score for all dairy goats was 2.4 ± 0.6 (Table 1). Alpines were the most reared breed of goat (41%), while Saanens were the least (8%) (Table 2). All the dairy goats encountered were hand-milked and mostly hand-mated. Of the does examined in Nakuru County, crosses represented

the highest percentage (51%). In Kericho, Kiambu and Nairobi County, Alpines were the majority. Saanen was only encountered in Kericho and Nairobi County. In Kiambu county, only lactating does of Alpine breed were encountered.

Figure 2

Box plot of body weight by breed

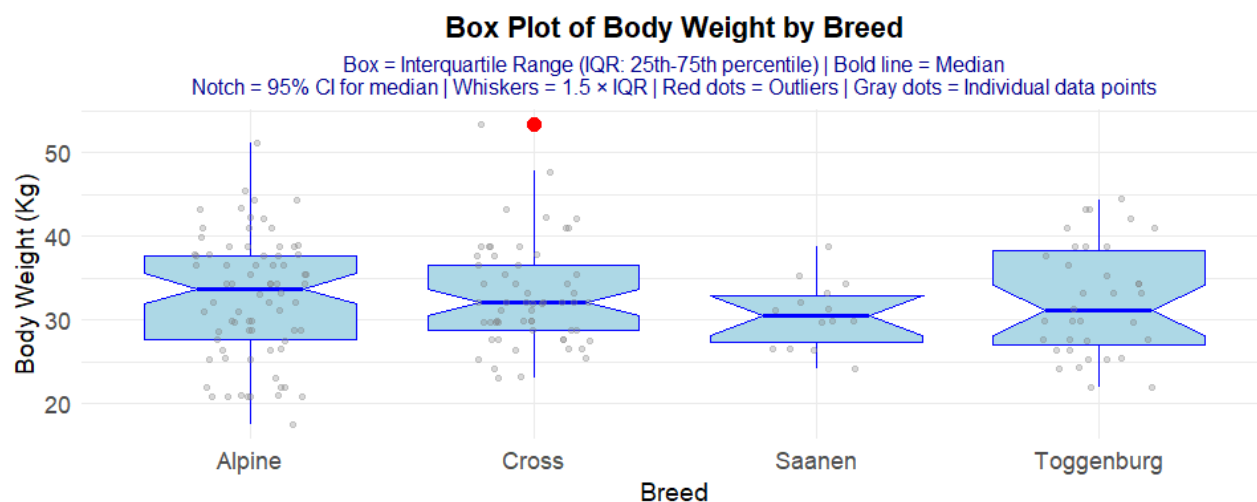


Table 1

Summary of body weight, age in months, and body condition scores (n=181)

Variable	Mean	SD	Range
Body weight (kg)	32.5	6.6	17.5 - 53.3
Age (months)	54.0	15.9	24 - 120
BCS	2.4	0.6	1.5 - 4.0
Parity	2.4 ± 1.5	1	7(1-8)

Table 2*Teat length (cm) and udder depth (cm) measurements in different breeds of lactating does (n=181)*

Breed (n, %)	Teat Length (cm)			Udder Depth (cm)		
	Mean	SD	Range	Mean	SD	Range
Overall	4.8	2.2	1.5-23.0	10.3	3.6	0.3-19.0
Alpine (74, 41%)	5.2	2.0 ^a	2.0-12.0	9.6	4.1	0.3-19.0
Cross (58, 32%)	4.5	1.5	1.5-9.0	11.0	3.3	3.0-18.0
Saanen (14, 8%)	4.6	1.0 ^a	3.0-7.0	8.8	2.5	5.0-12.0
Togg. (35, 19%)	4.7	3.4 ^a	2.7-23.0	11.2	2.9	6.0-18.0

Note. ^a Indicates breed-measurement combinations where potential outliers were identified based on a box plot analysis (Tukey's method). Overall median values were 4.5 cm for teat length and 10.0 cm for udder depth. Togg. = Toggenburg.

Teat length and udder depth

Teat length was moderately spread around the mean: 4.8±2.2 cm and a range of 1.5-23.0 cm, while udder depth showed greater variability: mean 10.3±3.6cm and range of 0.3-19.0 cm (Table 2). The mean and range of these measurements in various breeds (Table 2). Udder depth data was normally distributed ($W = 0.98935$, p -value = 0.1947), while teat length was not ($W=0.73667$, p -value < 2.2e-16). No significant associations were found between age and either teat length ($p = 0.864$) or udder depth ($p = 0.465$). Similarly, lactation stage (primiparous vs. multiparous) showed no significant effect on teat length ($p = 0.864$) or udder depth ($p = 0.465$).

Across breeds, Alpines had the longest teat

5.2±2.0 cm on average while Toggenburg had the deepest udder 11.2±2.9 cm (Table 2)

Teat length did not differ significantly between primiparous and multiparous does ($H = 0.029$; $df = 1$; $p = 0.864$) and showed no significant variation among breeds ($H = 7.017$; $df = 3$; $p = 0.071$). In contrast, udder depth varied significantly among breeds ($F = 3.414$; $p = 0.0187$), though Tukey's post hoc test found no significant pairwise differences (Table 3). All confidence intervals included zero, suggesting that observed differences were likely small and diffuse rather than due to specific breed effects. Additionally, udder depth showed no significant correlation with age ($r = 0.055$; $CI = -0.092$ to 0.199 ; $p = 0.465$).

Table 3*Comparisons of udder depth between dairy goat breeds: Tukey's HSD Post-Hoc Test*

Comparison	Difference	CI	P- adjusted
Saanen - Toggenburg	-2.400	[-5.282, 0.482]	0.1386
Cross- Toggenburg	-0.177	[-2.128, 1.774]	0.9954
Alpine - Toggenburg	-1.601	[-3.470, 0.269]	0.1217
Cross- Saanen	2.223	[-0.491, 4.937]	0.1494
Alpine - Saanen	0.799	[-1.857, 3.456]	0.8632
Alpine - Cross	-1.423	[-3.022, 0.175]	0.0996

Udder characteristics

Symmetrical udders were the most common (67%), followed by moderately symmetrical (19%) and asymmetrical (14%). Of the Alpines, 44% had

symmetrical (44%) and 48% asymmetrical, whereas 32% of the crosses had moderately symmetrical udders (Table 4). There was no significant relationship between udder symmetry

and body weight (F value 0.113; df :2; p value: 0.893) and age ($H = 0.153$, $df = 2$, p value = 0.9264). For the udder suspension classification, the intermediate was predominant (77%), over loose (17%) and attached (6%) (Figure 3). Alpines' udders accounted for the largest proportions of intermediate (38%) and loose (55%) suspensions. Attached udder suspension was most common in Toggenburgs (45%) (Table 4). Globular-shaped

udders were most prevalent (48%), followed by pear-shaped (40%) (Figure 4) and cylindrical (12%). Globular udders were most common in crosses (37%) and Alpines (34%). Pear-shaped udders were dominated by Alpines (49%). Cylindrical udders were equally represented by Alpines and Crosses (41% each) (Table 4).

Figure 3

Photograph of the udder of a 2-year-old, Alpine dairy goat breed with a globular-shaped, symmetrical and attached suspension udder. Note the moderately separated, oblique-positioned and funnel-shaped teats with pointed ends.

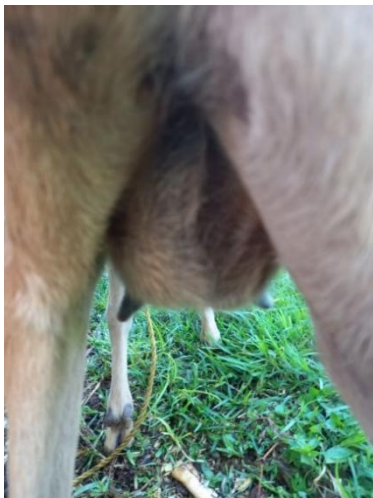


Figure 4

Photograph of the udder of a 4-year-old, Alpine (German) dairy goat breed with an intermediate suspension, pear-shaped, symmetrical udder. Teats are moderately separated, obliquely positioned, and funnel-shaped with pointed ends

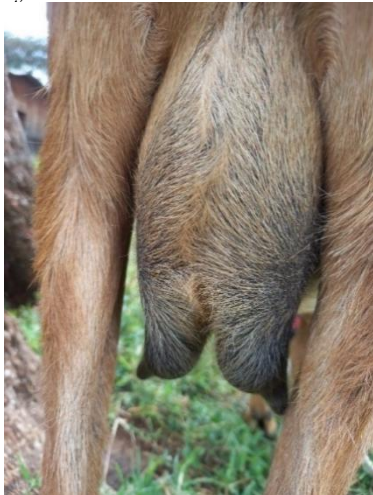


Table 4*Udder and teat traits distribution by breed (n = 181)*

Trait	Category	Total (n, %)	Alpine (n, %)	Cross (n, %)	Togg. (n, %)	Saanen (n, %)
Udder						
Symmetry	Symmetrical	122 (67%)	54 (44%)	40 (33%)	23 (19%)	5 (4%)
	Moderate	34 (19%)	8 (24%)	11 (32%)	8 (24%)	7 (21%)
	Asymmetrical	25 (14%)	12 (48%)	7 (28%)	4 (16%)	2 (8%)
Suspension	Intermediate	139 (77%)	53 (38%)	49 (35%)	27 (19%)	10 (7%)
	Loose	31 (17%)	17 (55%)	7 (23%)	3 (10%)	4 (13%)
	Attached	11 (6%)	4 (36%)	2 (18%)	5 (45%)	0 (0%)
Shape	Globular	86 (48%)	29 (34%)	32 (37%)	22 (26%)	3 (3%)
	Pear-shaped	73 (40%)	36 (49%)	17 (23%)	10 (14%)	10 (14%)
	Cylindrical	22 (12%)	9 (41%)	9 (41%)	3 (14%)	1 (5%)
Teat						
Placement	Oblique	118 (65%)	46 (39%)	36 (31%)	27 (23%)	9 (8%)
	Vertical	63 (35%)	28 (44%)	22 (35%)	8 (13%)	5 (8%)
Shape	Funnel	107 (59%)	47 (44%)	34 (32%)	21 (20%)	5 (5%)
	Bottle	63 (35%)	23 (37%)	22 (35%)	9 (14%)	9 (14%)
	Cylindrical	11 (6%)	4 (36%)	2 (18%)	5 (45%)	-
End Shape	Pointed	136 (75%)	54 (40%)	46 (34%)	26 (19%)	10 (7%)
	Blunt	45 (25%)	20 (44%)	12 (27%)	9 (20%)	4 (9%)
Separation	Moderate	153 (85%)	62 (41%)	51 (33%)	29 (19%)	11 (7%)
	Severe	21 (12%)	7 (33%)	5 (24%)	6 (29%)	3 (14%)
	Slight	7 (4%)	5 (71%)	2 (29%)	-	-

Note. Togg. = Toggenburg.**Teat characteristics**

Overall, oblique teat placement (65%) was more common than vertical (35%) (Table 4). Funnel-shaped were dominant (59%), followed by bottle-shaped (35%) (Figure 5) and cylindrical (6%) (Table 4). Pointed teat ends were predominant (75%), over blunt ends (25%). Most teats showed moderate separation (85%), with severe (12%) and slight separation (4%) being less common; slight separation was only seen in Alpine and Crossbred goats. Although teat length medians were non-normally distributed, they showed no significant difference across separation degrees (Table 2).

Relationship between udder suspension and udder depth

A significant effect of udder suspension on udder depth was observed ($F(2,178) = 5.30$; $p = 0.0058$). Tukey's HSD test showed that does with loose udder suspension had significantly shallower udders compared to those with attached (*mean difference* = 3.17 cm; $p = 0.0268$) and intermediate suspension (*mean difference* = 2.07 cm; $p = 0.0104$). No significant difference was detected between attached and intermediate suspensions ($p = 0.5422$) (Table 5).

Figure 5

Photograph of the udder of a 4-year-old, cross dairy goat breed with an intermediate suspension, globular-shaped, symmetrical udder. Teats are moderately separated, obliquely positioned, and bottle-shaped with pointed ends



Table 5

Udder depth in different categories of udder suspension

Udder suspension	Udder depth(cm)		
	Mean	SD	p-value
Attached	11.7	2.57	0.0268*
Loose	8.53	4.09	0.0104*
Intermediate	10.6	3.42	0.5422

Note. * $p < .05$.

Relationship between udder and teat characteristics and breed

Fisher's exact tests revealed significant associations ($p < 0.05$) among udder and teat traits, i.e. symmetry, suspension, shape, teat separation, placement, shape, end shape, and abnormalities, as well as their relationship with breed (Table 6). Notably, udder symmetry was linked to suspension and shape, while teat separation

correlated with suspension and placement. The likelihood of these distributions occurring by chance was low. Measures of association using Cramér's V are provided in Table 6. The summary of the significant associations of the udder and teat characteristics and breed are tabulated in Table 7.

Table 6*Cramér's V and Fisher's Exact Test p-Values for associations between breed and udder/teat characteristics*

	BRD	USM	DTS	USN	TP	TS	TES	USH	UTA
BRD	1	.19 (.054)	.13 (.433)	.18 (.113)	.12 (.427)	.18 (.115)	.07 (.831)	.20* (.025)	.18 (.669)
USM	–	1	.19** (.009)	.20** (.01)	.11 (.361)	.14 (.158)	.08 (.584)	.19** (.006)	.19 (.264)
DTS	–	–	1	.22** (.002)	.33** ($<.001$)	.05 (1.000)	.06 (.860)	.18* (.019)	.36** (.008)
USN	–	–	–	1	.09 (.561)	.08 (.614)	.17 (.075)	.35** (.000)	.19 (.184)
TP	–	–	–	–	1	.01 (1.000)	.06 (.471)	.07 (.608)	.23 (.056)
TS	–	–	–	–	–	1	.21* (.018)	.13 (.188)	.17 (.207)
TES	–	–	–	–	–	–	1	.09 (.452)	.17 (.400)
USH	–	–	–	–	–	–	–	1	.28* (.021)
UTA	–	–	–	–	–	–	–	–	1

Note. Values are Cramér's V, with Fisher's Exact Test p-values shown in parentheses.

Significance indicators: * $p < .05$, ** $p < .01$. BRD = Breed, USM = Udder symmetry, DTS = Degree of teat separation, USN = Udder suspension, TP = Teat placement, TS = Teat shape, TES = Teat end shape, USH = Udder shape, UTA = Udder and teat abnormality.

Table 7

Significant associations among udder and teat characteristics and breed. (Detailed Cross-Tabulations Available in Supplementary Materials- Supplemental Table S1-11.)

ST ref.	Variables Pair	p-value	Key association/pattern observed
S1	Breed vs Udder Shape	0.032	Saanen had the highest % of pear-shaped udders; cross breeds were mostly globular
S2	Udder Symmetry vs Udder Suspension	0.008	Symmetrical udders mostly intermediate suspension; asymmetrical: loose
S3	Udder Symmetry vs Udder Shape	0.008	Symmetrical: mostly globular; asymmetrical: mostly pear-shaped
S4	Udder Symmetry vs Teat Separation	0.011	Symmetrical udders: mostly moderate separation; asymmetrical: severe
S5	Udder Suspension vs Udder Shape	0.000	Attached udders: 100% globular; loose: mostly cylindrical
S6	Udder Suspension vs Teat Separation	0.004	Loose udders: highest % of severe separation
S7	Udder Shape vs Teat Separation	0.017	Globular: mostly moderate; cylindrical: more severe
S8	Teat Separation vs Teat Placement	0.000	Severe separation: 100% oblique; slight: mostly vertical
S9	Teat Shape vs Teat-End Shape	0.013	Funnel teats: 82% pointed ends; cylindrical: mostly blunt
S10	Teat Separation vs Udder/Teat Abnormalities	0.004	Severe: more fused teats; slight: more supernumerary/cyst
S11	Udder Shape vs Udder/Teat Abnormalities	0.022	Pear-shaped udders: more abnormalities (forked/fused teats)

Note. ST ref.= Supplemental table reference

Discussion

In this era of climate change, resource-poor farmers are increasingly adopting dairy goat farming as a poverty alleviation strategy, with goats providing nutritious milk for the homestead, generating income while being less capital-intensive. In this study, the aim was to elucidate the udder and teat characteristics of dairy goats in Kenya, which heavily influence the lifetime productivity of dairy goats.

In this study, the predominant breeds were of alpine genotype (41%) while one fifth (19%) were Toggenburg. This over-representation of alpiners was due to the fact that all alpiners' variants, i.e. Kenyan, German, French and British alpiners, were all placed into alpine category. The strong preference for Alpiners is likely due to higher milk production. As reported by Waiveina *et al.* (2021),

Alpiners had higher milk yield (1.83 ± 0.12 litres) as compared to Toggenburg (1.70 ± 0.13 litres) and have adapted to humid and sub-humid regions in Kenya (Mburu *et al.*, 2014). The Saanen breed had the lowest prevalence (8%) among lactating does in this study, and we postulated these low numbers is due to Saanen breed being less adaptable and resistant to diseases as it has been reported by other authors (Gökdağ *et al.*, 2020; Gore *et al.*, 2020). However, a previous study suggested that reasons for the choice of one breed as regards production and survivability in a region were shown not to favour any particular breed (Kiura *et al.*, 2020). When selecting breeding does and bucks, farmers were not breed specific as mentioned in other studies where there were preferences for Kenyan Alpine, Toggenburg, and Saanen in that order over indigenous (Jesang, 2022). These findings are consistent with those of other authors who pointed out a disregard for the breed type so long as it was exotic (Gicheha *et al.*,

2023).

The evenness and balance between the two udder halves (left and right) was evaluated and scored across the breeds. Symmetrical udders were more common, with a 67% occurrence. This is a good indication as symmetrical udders have been linked to lower somatic cell count (SCC), indicating better udder health and reduced intra-mammary infections (IMI) risk (Margatho *et al.*, 2020). The percentage distribution of symmetry agrees with findings by Khasanah *et al.* (2024) and Margatho *et al.* (2020) where symmetrical udders were more common. The occurrence of udder asymmetry was higher (48%) in Alpines than in other breeds although these relationships were not significant. A report by Amao *et al.* (2003) did show a low frequency (5.7%) of asymmetrical udders, whereas in a study by Atay and Gokdal (2016), 28% asymmetrical udders were reported. In other studies, Saanen were reported to have distorted udder morphologies due to increase pressure on udder suspensory ligaments since it is considered a high milk producer (Vrdoljak *et al.*, 2020), however, our findings did not indicate the same. Breed difference has been suggested in the difference congruency of goat udders. For example, Kalahari Red goats have a higher incidence of asymmetrical udders (about 10.6%) compared to West African Dwarf goats (WAD), where only 6.4% show this trait; most WAD goats (over 93%) have symmetrical udders (Amao *et al.*, 2003; Bemji *et al.*, 2016). There was no significant relationship between udder symmetry and body weight (F value 0.113; df : 2; p value: 0.893) and age (H = 0.153, df = 2, p value = 0.9264) which disagrees with findings by Upadhyay *et al.* (2014) who concluded that all udder and morphological traits have positive and significant correlation with body weight and different intervals.

Intermediate udder suspension was more common category (77%), a finding that is in agreement with reports on Serrana goats by Margatho *et al.* (2020). Attached udders have been associated with minimal occurrence of udder infection in goats (de Cremoux *et al.*, 2024). In the companion study, udder suspension did not seem to significantly affect incidence of subclinical mastitis in univariable logistic regression ($p > 0.05$). In all levels of udder suspension, intermediate suspension was the commonest

followed by loose then lastly attached ($p = 0.01$). All other udder characteristics were not significantly related to breed, except udder suspension. Recent genome-wide association analysis in Murciano-Granadina goats has identified specific genetic markers, particularly on chromosomes 16 and 28, that are significantly associated with udder suspension traits linked to the medial suspensory ligament (Luigi-Sierra *et al.*, 2020).

Majority of does in this study had globular-shaped udders (48%), which have been reported to be more prevalent in commercial dairy goats (Margatho *et al.*, 2020). The globosity of udder, as determined by combined effect of udder depth and distance between teats, is more valuable in regard to functional longevity, milk production and milkability, functional longevity (Capote *et al.*, 2006; Palhière *et al.*, 2018). The strong and significant association observed between udder shape and suspension ($V = 0.346$; $p < 0.001$) showed that all does that had attached suspension were globular udders while a majority of loose suspension were cylindrical (42%), pear (35%) and globular shaped (23%). It can be argued that the udder suspension affects the outline and appearance of the udder shape. Of key consideration is whether the "attached suspension" inherently favours the formation of "globular udders" or merely influences the "globular outline" since it may impact the degree of support and positioning and hence shape. The estimated breeding values (EBVs) for milk yield and the suspensory system are reported to have a negative association (Manfredi *et al.*, 2001). This suggests a trade-off between selecting for higher milk yield and maintaining well-suspended udders.

Teat length in dairy goats is significant as it positively correlates with milk yield (Akpa *et al.*, 2003), influences milking efficiency by affecting milking time and speed and is crucial for selecting appropriate teat cup liners, which impact both milking efficiency and udder health (Peris *et al.*, 1999). In this study, the average length of the teat was 4.8 ± 2.2 cm with a range of 1.5-23.0cm across the breeds, consistent with that of Makau (2017) who reported predominance of teat >3 cm. The difference in teat length among dairy breeds was non-significant ($p = 0.07135$), with Alpines having longer teats than the rest of the breeds. Unlike the

findings by James *et al.* (2009), age was weakly positive and non-significantly correlated with the teat length. Local breeds like the West African Dwarf goats, Bedouin goats, and Murciano-Granadina dairy goats have been reported to have smaller teat length compared to the findings of the current study (Peris *et al.*, 1999; James *et al.*, 2009; Kouri *et al.*, 2018). Upadhyay *et al.* (2014), Margatho *et al.* (2020) and Gupta *et al.* (2023) reported teat lengths longer than those of this study in Jamunapari, Serrana and Indian local goats, respectively. Further, Szymanowska *et al.* (2010) reported longer teat lengths for Saanen goats (6.8 ± 1.9 cm) compared to those in this study (4.6 ± 1.0 cm). Teat length in dairy goats had been reported to have generally positive but modest correlation with milk yield, meaning that goats with longer teats tend to produce more milk, though the relationship is not as strong as with other udder traits like udder circumference or volume (Peris *et al.*, 1999; Akpa *et al.*, 2003; Jena *et al.*, 2019).

According to this study, udder depth showed greater variability (10.3 ± 3.6 cm). The depth ranged from 0.3-19.0 cm. There were no breed differences in udder depth. In general, for high yielding dairy goats, among other characteristics, medium depth that do not exceed height at the hocks is optimal which was echoed in our study where no udder depth measurements took a negative value (Gall, 1980).

While comparing means of udder depth across different groups of udder suspension, a significant effect of udder suspension on udder depth was revealed ($F(2, 178) = 5.301, p = 0.0058$), as the udder get closer to the tibio-tarsal joint, so as suspension transit from attached to loose udders. This is consistent with the observation by Margatho *et al.* (2020) that the bigger the positive difference was, the more attached the udder became. Smaller depth had been seen in loose vis-à-vis attached udders (Margatho *et al.*, 2020). Teat length and udder depth had a significant though weak negative correlation ($\rho = -0.1904947, p\text{-value} = 0.01021$). This is in partial agreement with findings by Margatho *et al.* (2020) ($\rho = -0.445, p\text{-value} = 0.01$). Thus, according to our study, as the teat length increases, the udder gets deeper, albeit slightly. Szymanowska *et al.* (2010) reported that Saanen had a greater udder depth (though methodology differ) and longer

teats.

The most prevalent degree of teat separation in our study was moderate (85%), which has been similarly reported in other studies (Margatho *et al.*, 2020; Khasanah *et al.*, 2024). This study reports a significant relationship between degree of teat separation and udder suspension, teat placement, udder shape and udder and teat abnormality. Intermediate state of suspension is associated with moderate separation of teat. In slightly separated teats, there is a high chance of cross-contamination, teats rubbing each other and difficulty in hand milking and the placement of cups during machine milking. The findings indicate that as udder suspension becomes looser, a higher proportion of cases exhibit severe teat separation compared to udders with firmer attachment. This suggests a potential trend associating looser udder suspension with a more pronounced degree of teat separation. Severely separated teats are usually seen in pendulous udders (Margatho *et al.*, 2020). The distance between teats correlates with milk yield in goats, with greater teat separation positively influencing milk production (Makamua *et al.*, 2023). Unlike our study, Khasanah *et al.* (2024) observed a significant relationship between the degree of teat separation and udder symmetry and also with teat shape (both at $p = 0.01$; 1-tailed).

Funnel-shaped teats were common in our study (59%), contrary to James *et al.* (2009), who reported more predominant cylindrical teats in WAD goats. In many breeds of goats, a cylindrical shape is more desirable due to better milk production and has been linked to lowered somatic cell count (Margatho *et al.*, 2020; de Cremoux *et al.*, 2024). Pointed teat ends were more common (75%) in our study, which contrasts with Amao *et al.* (2003) who reported that the majority of WAD goats had blunt/round teat ends (88.6%). In the same study, blunt/round teat ends were more common (96.1%) in Red Sokoto goats.

In our study, teats were either obliquely placed (65%) or vertical placed (35%) as viewed from behind, which agrees with the findings of other studies (Amao *et al.*, 2003; James *et al.*, 2009). All teats with a severe degree of separation (160-180) had oblique placement, while the majority (86%) of slightly separated teats had vertical placement.

Teats implanted in a near vertical position are ideal for uninterrupted milk removal during machine milking and ease of milking (Labussière, 1988; Marnet *et al.*, 2024). Selection of good udder conformation can decrease mastitis susceptibility (Margatho *et al.*, 2020).

Conclusion

Teat length shows a slight positive association with udder depth, although it did not significantly vary by breed or parity. Udder depth varies across breeds and is influenced by udder suspension; deeper udders are associated with looser suspension, which alters udder shape and teat separation. Attached udders are typically globular with slight teat separation, while looser udders often exhibit severe separation and oblique teat placement. Teat shape influences teat end shape, with funnel-shaped teats and blunt ends being relatively uncommon. These findings suggest that udder and teat traits are interconnected and could influence dairy goats' functional efficiency and management practices.

Recommendation

Based on the findings, this study recommends prioritization of selection for globular udders and attached/intermediate suspension. Avoid breeding goats with pendulous udders or severe teat separation to reduce mastitis risk. Favour cylindrical teat shapes over funnel-shaped ones.

Declaration of interest

None

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