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Phenotypic diversity and milk production performance of Somali camel ecotypes under extensive pastoral systems

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Somali pastoralists recognise four primary dromedary camel (*Camelus dromedarius*) ecotypes—Hoor, Aiden, Gellab, and Sifdacar based on conformation, coat characteristics, and perceived production utility; however, quantitative description of these classifications remains poorly documented. This study evaluated the phenotypic diversity and milk production performance of these ecotypes under extensive management systems. A cross-sectional survey was conducted on 472 mature camels across the Banadir, Bay, Galgaduud, Gedo, and Lower Shabelle regions of Somalia. Eighteen linear body measurements and multiple qualitative traits were recorded, alongside daily milk production monitoring for lactating females. Animals were stratified and analysed by ecotype, sex, and two age class (8–11 and 12–15 years). Live body weight was estimated via a barymetric equation, and ecotypic means were compared using a one-way analysis of variance (ANOVA) followed by Duncan's multiple range test. The results confirmed significant phenotypic differentiation among the ecotypes. Among breeding males aged 8–11 years, the Aiden ecotype exhibited the highest estimated body weight (430 ± 30.2 kg, mean $\pm$ SEM), whereas Sifdacar displayed the greatest height at withers (161.0 ± 7.44 cm), and facial length (57.0 ± 2.26 cm). Within the older male cohort (12–15 years), Aiden remained the heaviest (500.88 ± 38.14 kg), whereas Sifdacar males exhibited the lowest (361.80 ± 48.24 kg), while Sifdacar retained distinctive structural frame traits despite a lower body mass. Qualitative assessments characterised Hoor females by relatively larger udder and teat dimensions. Despite these distinct morphological divergences, milk production varied minimally among groups. Mean daily milk yield ranged from 7.24 to 7.70 L/day, and the overall ecotype effect was statistically non-significant ($P = 0.814$). These findings validate indigenous pastoral knowledge, demonstrating that Somali camel ecotypes represent morphologically distinct biocultural resources. Furthermore, the data suggest that under extensive production frameworks, daily milk yields are heavily modulated by environmental and management factors rather than ecotypic identity alone.

This study establishes a foundational morphometric and production baseline to support community-based breeding programs, advance animal genetic resource conservation, and strengthen the camel dairy value-chain development in Somalia.

KEYWORDS

Camelus dromedarius, biocultural resources, indigenous knowledge, morphometric traits, milk yield, population characterisation

Introduction

The one-humped camel (*Camelus dromedarius*) is a defining livestock species of the drylands. It is valued for its capacity to utilise sparse browse, tolerate erratic water availability, and provide milk, meat, transport power and household security under environmental conditions that severely constrain other domestic species (Bulliet, 1990; Burger et al., 2019; Faye, 2020; Ismail, 1987; Kadim et al., 2008; Zarrin et al., 2020). In arid and semi-arid pastoral systems, camels are not merely substitutes for cattle or small ruminants; they are central to risk buffering, mobility and livelihood continuity because they can remain productive during drought and under variable forage conditions (Herrero et al., 2016; Mirkena et al., 2012; Monaco, 2025; Nagy et al., 2022).

In the Horn of Africa, and particularly in Somalia, the socioeconomic importance of camels is exceptionally high. Camel milk is a key food in pastoral households, a culturally valued commodity, and is becoming an increasingly commercial product in peri-urban and urban markets (Farah et al., 2007; Farah and Fischer, 2004; Younan and Mwangi, 2012). Somalia is also one of the world's major camel-holding countries, which makes the species important not only for household nutrition and income but also for national livestock development planning (Faye, 2020; Zhu et al., 2019). At the same time, increasing market integration, disease risks and climate stress are reshaping camel production systems across the region, demanding the need for stronger evidence on the biological diversity that underpins resilient production system (Gossner et al., 2016; Herrero et al., 2016; Mirkena et al., 2018; Nagy et al., 2022).

Recent global reviews further show that camel milk and meat are gaining importance in international discussions of food security, value-chain development, product quality and market efficiency (Ait El Alia et al., 2025; Boukrouh et al., 2025; Boukrouh et al., 2026a; 2026b). Analytical tools for detecting adulteration in camel milk products also highlight the growing need for better quality control as camel value chains expand (Ait El Alia et al., 2026).

Somali pastoralists do not regard camels as a uniform population. Rather, they distinguish named ecotypes on the basis of body conformation, coat characteristics, production purpose, temperament, movement ability and perceived adaptation to production environments. In Somali husbandry literature and pastoral knowledge, the ecotypes most consistently recognised are Hoor, Aiden, Gellab and Sifdacar (Abdirisak, 2023; Baumann and Zessin, 1992; Elmi, 1989; Hussein, 1988). Such pastoral classification systems are important because they represent cumulative local selection and long-term observation, and they frequently encode biologically meaningful distinctions that formal livestock science should document rather than overlook (FAO, 2008; Köhler-Rollefson, 2022). However, findings from other camel

populations cannot be directly extrapolated to Somalia because local ecotypes are shaped by Somalia-specific pastoral history, mobility patterns and production environments. This creates a specific need for systematic Somali data linking pastoral classifications with measured phenotypic and milk-production traits. Therefore, documenting measurable phenotypic variation is necessary to determine whether locally recognised Somali camel ecotypes correspond to quantifiable biological differences and to clarify their relevance for production, breeding, and conservation. Studies across Africa and Asia consistently report measurable phenotypic differentiation among camel ecotypes or breeds in body size, frame, coat type, udder traits and other external characteristics (Akhmetsadykova et al., 2023; Bekele et al., 2018; Ehsaninia et al., 2020; Ishag et al., 2010; Ishag and Ahmed, 2011; Legesse et al., 2018; Tandoh et al., 2018; Yosef et al., 2014). Recent methodological reviews further emphasise that structured phenotypic description remains a necessary complement to emerging genomic characterisation approaches for breed documentation, breeding-objective definition and conservation of under-described camel genetic resources (Alhajeri et al., 2019; 2021; Yakubu et al., 2022). For Somali camels, however, the quantitative evidence base remains thin. Much of the literature is descriptive, geographically narrow, or focused on health, husbandry and milk marketing rather than critical comparison of ecotypes across regions and age–sex classes (Abdirisak, 2023; Baumann and Zessin, 1992; Farah et al., 2007).

This gap matters because phenotypic diversity is the operational starting point for the sustainable use of animal genetic resources (FAO, 2008). It also matters because emerging genomic work indicates that camel populations can retain substantial within-population diversity even when visible types are locally recognised, which means that careful phenotypic recording is essential for interpreting the relationship between traditional ecotypes, adaptive traits and potentially associated genetic structure (Alaqeely et al., 2021; Ali et al., 2019; Al-Swailem et al., 2010; Bagiyal et al., 2024; Bahbahani et al., 2019; Piro et al., 2020; Piro, 2021). The production relevance of ecotype differentiation is especially important for milk.

Somali pastoralists often attribute higher dairy value to some ecotypes than others, yet milk yield in camels is influenced by many interacting factors, including parity, stage of lactation, reproductive status, nutrition, water access, calf management and general herd husbandry (Ainani et al., 2022; Al haj and Al Kanhal, 2010; Ali et al., 2018; Bekele et al., 2002; Gebremichael et al., 2019; P. Nagy and Juhasz, 2016; Nagy et al., 2022). Consequently, reputational differences in dairy performance do not always translate into large field-level differences in reported daily milk offtake, especially under heterogeneous extensive systems (Farah et al., 2007; Zarrin et al., 2020). The present study quantified the phenotypic diversity and reported daily

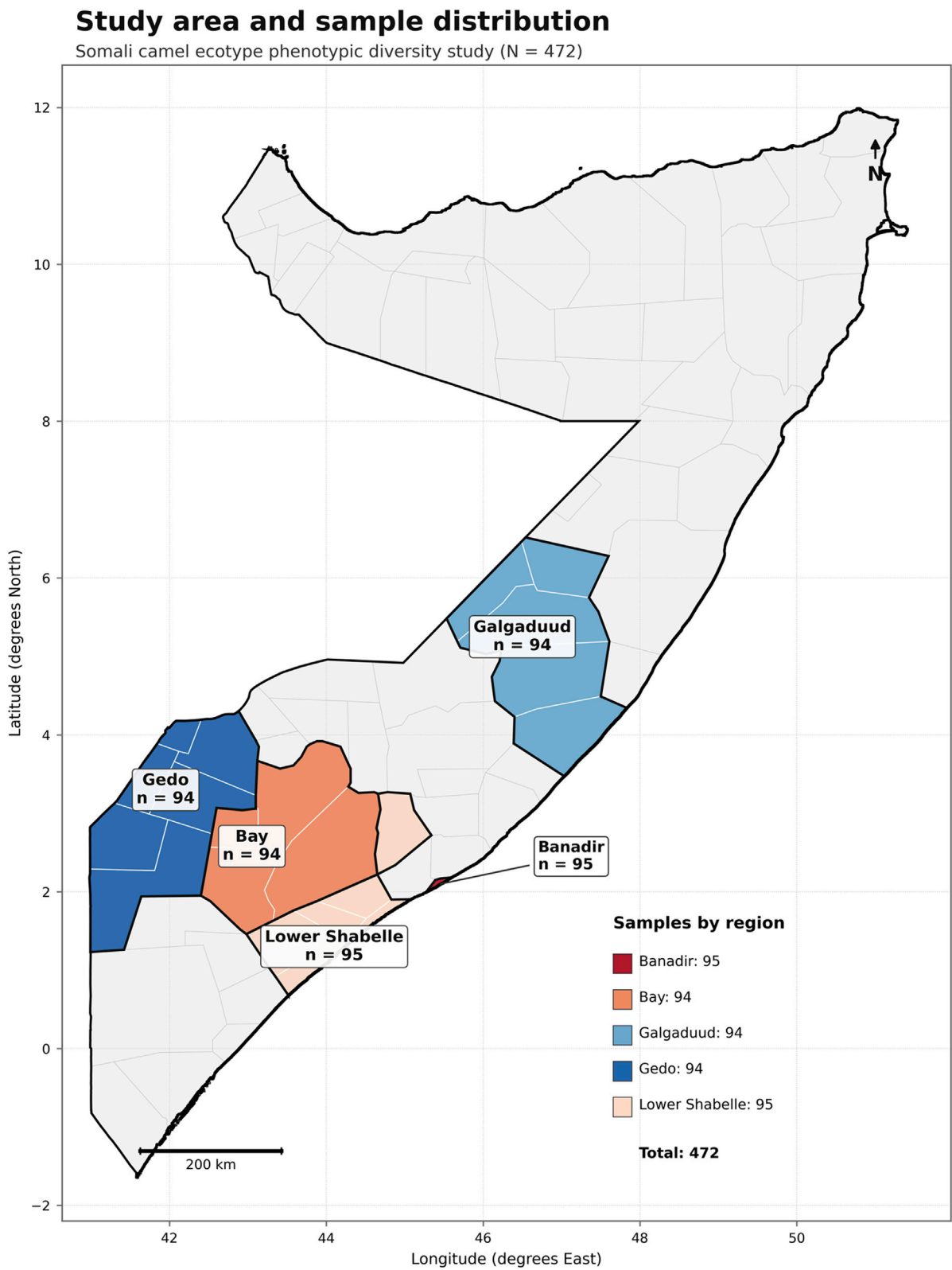


FIGURE 1
Study area and sample distribution of Somali camel ecotypes across five regions of South and Central Somalia. Numbers indicate sampled animals per region.

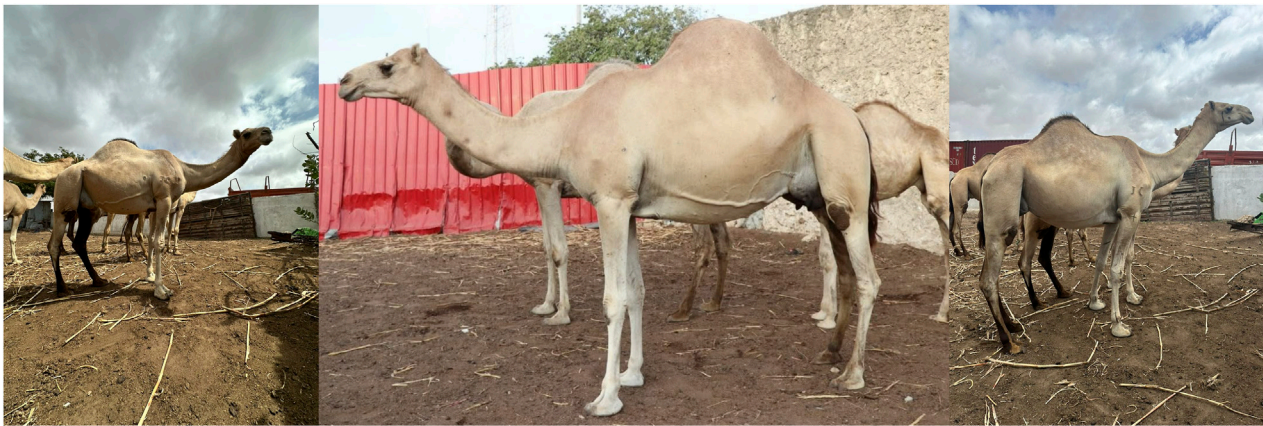


FIGURE 2
Herds sampled mature camels.

milk offtake of four Somali camel ecotypes under extensive pastoral management. Specifically, we compared qualitative traits, linear body measurements and estimated body weight across ecotypes, sex and age classes, and evaluated whether reported daily milk offtake differed among ecotypes. We hypothesised that Somali ecotypes would show clearer morphometric differentiation compared with milk production differentiation because environmental and management factors substantially influence dairy performance under extensive systems.

Materials and methods

Study area

The study was conducted in five regions of South and Central Somalia: Banadir, Bay, Galgaduud, Gedo, and Lower Shabelle (Figure 1). The regional sample distribution was Banadir ($n = 95$), Bay ($n = 94$), Galgaduud ($n = 94$), Gedo ($n = 94$), and Lower Shabelle ($n = 95$), giving a total sample size of 472 mature camels (Figure 1). These regions represent important camel-keeping environments spanning dry inland rangelands, agro-pastoral zones, and comparatively more humid coastal and riverine areas. Therefore, the study area captured a broad ecological gradient within Somalia's pastoral production landscape while remaining focused on regions where the target ecotypes were accessible under field conditions. These regions are characterised by arid to semi-arid climates, variable rainfall, high temperatures, and extensive livestock mobility, all of which shape camel management and performance.

Because the study covered heterogeneous production environments, region was considered an important contextual factor. Banadir and Lower Shabelle include coastal, peri-urban, riverine, and agro-pastoral settings, whereas Bay, Gedo, and Galgaduud include drier inland pastoral and agro-pastoral landscapes with variable browsing resources, water access, and herd mobility. Exact herd-level coordinates, altitude, rainfall, temperature, vegetation composition, and management variables were not consistently available for all sampled herds; this limited the

ability to separate ecotype effects from environmental and regional effects.

Study design, animals and sampling

A cross-sectional field survey was conducted using structured interviews and direct phenotypic assessments. Herds were identified through local pastoral networks, field contacts, and owner willingness to participate, and animals were selected from mature camels within accessible herds. Therefore, the sampling should be interpreted as field-based sampling of available owner-identified ecotypes rather than a fully probabilistic sample from a complete regional camel census. The sample comprised 472 mature camels, including 188 males and 284 females (Figure 2). Ecotype identity was initially reported by owners using locally recognised names and was checked against the external phenotypic criteria used by field staff, including body conformation, coat characteristics, and qualitative traits. Ecotype assignment was checked by trained field staff using agreed external phenotypic criteria; however, a formal inter-observer agreement statistic was not assessed and should be recognised as a field-classification limitation. Age was estimated using a combined assessment of owner/herder recall and dentition, including tooth eruption pattern, tooth wear, and general dental condition. When owner information and dentition were inconsistent, the dentition-based estimate was prioritised for age-class assignment; animals with highly uncertain age estimates were not included. Camels younger than 8 years were excluded to ensure the analysis focused on animals with stable adult morphology, while animals older than 15 years were excluded to minimise confounding from advanced age, tooth wear, and age-related changes in body condition. The animals were grouped into two age classes: 8–11 years and 12–15 years. This stratification allowed for ecotype comparisons within broadly comparable adult maturity classes. The sample size was based on the availability of mature animals from the four owner-identified ecotypes across the study regions and was considered sufficient for descriptive comparisons within age-sex strata. Accordingly, the study should be regarded as a field-based characterisation survey rather than a controlled genetic or longitudinal production trial.

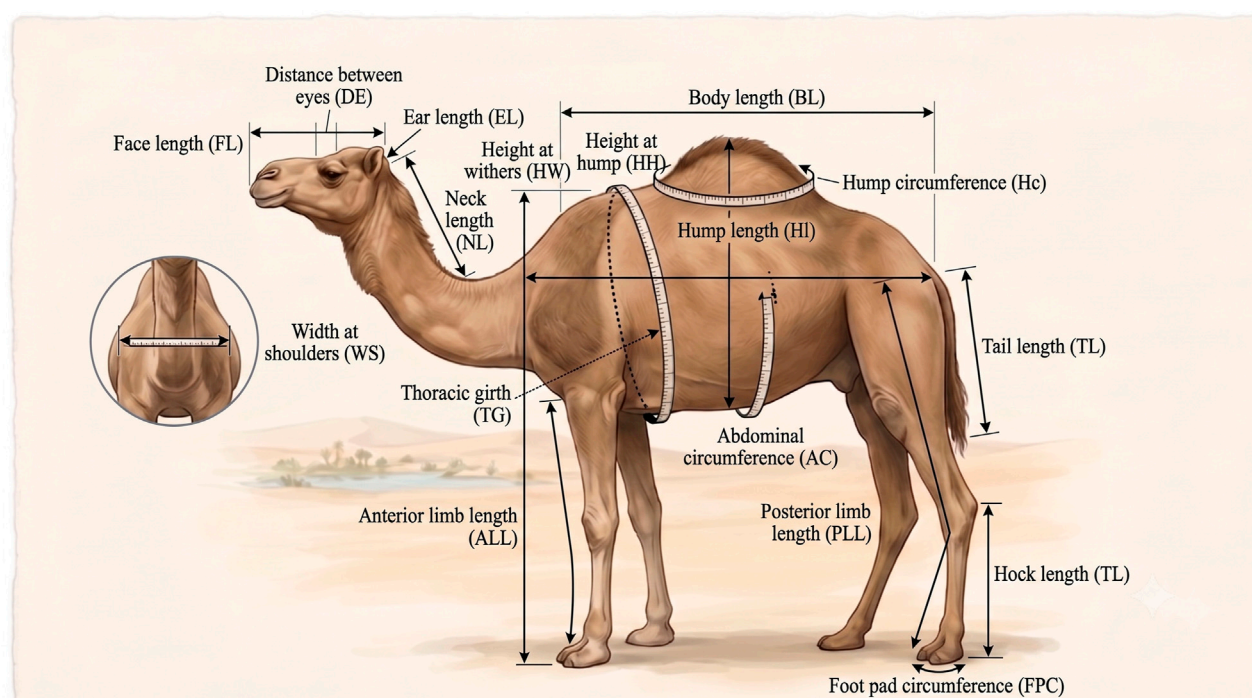


FIGURE 3
Morphometric reference chart for the one-humped camel (*Camelus dromedarius*). Arrows indicate the standard measurement points for eighteen different linear body traits utilized in the phenotypic assessment (the image was generated using Google Gemini).

Phenotypic characteristics

Qualitative phenotypic observations considered in the study were face profile (facial measurements), ear size and orientation, body colour and colour pattern, hair type and length, hump size and position, and udder and teat characteristics in females, following the FAO framework for phenotypic characterisation of animal genetic resources (FAO, 2008).

Linear body measurements

The quantitative traits included in the study were 18 linear body measurements recorded in centimetres (cm), namely, face length, distance between the eyes, ear length, neck length, width at shoulders, height at withers, thoracic girth, anterior limb length, height at hump, abdominal circumference, hump length, hump height, hump circumference, body length, posterior limb length, tail length, and foot-pad circumference (Figure 3). These measurements were taken with the animal standing on level ground, using a measuring tape and a measuring stick for height traits. Face length was measured along the face from the frontal/nasal region to the muzzle; distance between the eyes was measured between the medial eye margins; ear length was measured from the ear base to the tip; neck length was measured from the head-neck junction to the shoulder region; height at withers was measured vertically from the ground to the highest point of the withers; thoracic girth was measured around the chest immediately behind the forelimbs; abdomen circumference/barrel girth was measured around the widest part of the abdomen; body length was measured from the

shoulder point to the pin-bone region; tail length was measured from the tail base to the tip; and foot-pad circumference was measured around the pad. Limb and hump measurements were recorded using the same field landmarks throughout the survey. The variable coded as width at shoulders (WS) refers to the shoulder-region field measurement used in this survey and should not be interpreted as a simple skeletal transverse shoulder width measurement. The measurement landmarks shown in Figure 2 were checked against the field recording sheet and harmonised with the trait names used in the Methods and tables. For data quality, field data collectors were trained prior to data collection, and a common recording sheet and measurement protocol were used. Measurements were checked in the field by the lead recorder when more than one field worker was present. Values that appeared to be extreme during data analysis were rechecked against the available data files and interpreted cautiously where they could not be fully resolved.

Estimation of live body weight

Live body weight was calculated indirectly from shoulder height, thoracic girth, and barrel girth/abdomen circumference using the barymetric formula described by Yagil (1994). The estimated body weight (in kg) was calculated as follows:

$$BW = SH \times TG \times BG \times 50$$

where BW = estimated live body weight (kg), SH = shoulder height (m), TG = thoracic girth (m), and BG = barrel/abdomen circumference (m).

Shoulder height, thoracic girth, and barrel girth/abdomen circumference were combined after conversion to metres. This approach was used because direct camel weighing facilities were not practically available under field conditions. The equation was retained because no Somali camel ecotype-specific validated alternative was available and because it enabled approximate comparative assessment across animals under field conditions. Because a Somali-ecotype-specific validation or accuracy estimate for this equation was not available, estimated body weight should be interpreted as an approximate field indicator rather than as a direct measurement of live weight. Measurement errors in shoulder height, thoracic girth, or barrel girth/abdomen circumference may propagate into the body-weight estimate. Estimated body weight was reported in kilograms and analysed as a quantitative trait.

Milk yield data

Milk production data were collected from lactating females. Daily milk yield was recorded as owner-reported milk offtake rather than direct measurement of total biological production. Herders reported the milk obtained from morning and evening milking using their own familiar local milking containers; these containers were standardised by the study team. Before standardisation by the study team, variation in local container size and fill level may have introduced additional measurement error into reported offtake estimates. Reported quantities were converted to litres during data entry, and the recall period was limited to 1–2 days to reduce recall bias. This short recall period likely reduced, but did not eliminate, recall and rounding error. Because calf suckling, residual milk, and total biological production were not directly measured, reported offtake is likely to underestimate total biological milk production. However, container-based reporting and rounding may cause either over- or under-estimation of human offtake. Key factors affecting milk yield include calf suckling before or after milking, residual milk, calf age, parity, stage of lactation, pregnancy status, health status, diet, watering frequency, and season, although these were not consistently recorded. Accordingly, the milk data should be interpreted as descriptive owner-reported milk-offtake information. Only females that were actively lactating during the 1–2-day recall period were included. A total of 128 lactating cows (45% of the 284 camels sampled) were used for ecotype comparisons of daily yield, with 32 animals in each ecotype.

Statistical analysis

Data entry was performed in Microsoft Excel, and subsequent statistical analyses were conducted in R (version 4.2.2). Descriptive statistics were calculated for all variables. Differences between means in morphometric traits across ecotypes were assessed using one-way analysis of variance (ANOVA), following inspection of residual patterns and variance homogeneity. For significant ecotype effects (P -value < 0.05), Duncan's multiple range test was employed for *post hoc* mean separation, and results are presented as means $\pm$ standard errors of means (SEM).

Morphometric data were stratified by sex and age class, and milk production variation among ecotypes was evaluated using

descriptive statistics and ANOVA. For the multivariate morphometric analysis, to complement the univariate comparisons, exploratory multivariate analysis was conducted using the available individual-level morphometric records. The 18 quantitative traits, including estimated body weight, were standardised before analysis. Principal component analysis (PCA) was used to visualise the overall morphometric structure and ecotype overlap. To evaluate classification accuracy, a linear discriminant analysis (LDA) with stratified cross-validation was performed. Additionally, unsupervised k -means clustering ($k = 4$) was used to assess whether natural groupings corresponded to the designated pastoral ecotype labels. These methods were used for complementary purposes: PCA provided an unsupervised visual summary of overall morphometric structure and overlap, LDA provided a supervised assessment of how well measured traits classified known ecotypes, and k -means clustering provided an unsupervised test of whether natural groupings aligned with pastoral ecotype labels.

Results

Qualitative differentiation among ecotypes

Qualitative assessment revealed consistent morphological distinctions among the four studied ecotypes. While all ecotypes exhibited a straight-to-convex facial profile and erect ears, they varied distinctly in ear size, coat pattern, hair type, and mammary characteristics. The Hoor ecotype was characterised by a diverse colour palette, medium-to-long hair, and relatively large udders and teats. Conversely, Aiden and Gellab individuals displayed varied coat colours alongside generally larger ears. The Sifdacar ecotype was uniquely distinguished by a highly uniform light grey to greenish-grey coat and a consistent colour pattern. These empirical observations align closely with traditional pastoral classifications, confirming that Somali camels comprise recognisable ecotypes with distinct phenotypic appearances (Table 1).

Morphometric analysis of males aged 8–11 years

Marked morphometric divergence was observed among younger adult males (Table 2). Sifdacar males exhibited the greatest facial length (57.0 ± 2.26 cm, mean $\pm$ SED) and the highest mean height at withers (161.0 ± 7.44 cm). Aiden males exhibited the highest estimated mean body weight (430 ± 30.2 kg), whereas Gellab males displayed the largest thoracic girth (193.0 ± 11.51 cm). Significant ecotypic differences were also detected in neck length, shoulder width, anterior and posterior limb lengths, tail length, foot-pad circumference, and several hump dimensions (Table 2).

Morphometric analysis of females aged 8–11 years

Among females within the 8–11 years age cohort, significant ecotypic variation was observed across multiple dimensions (Table 3). Aiden females recorded the longest facial length

TABLE 1 Qualitative description of camel traits in Somali ecotypes.

Qualitative trait	Hoor	Aiden	Gellab	Sifdacar
Face profile	Straight to convex	Straight to convex	Straight to convex	Straight to convex
Ear size	Small to medium	Large	Large	Small to medium
Ear orientation	Erect	Erect	Erect	Erect
Body colour	Diverse palette: brown shades, red shades, grey, black, and light white	Diverse palette: brown shades, red shades, grey, black, and light white	Diverse palette: brown shades, red shades, grey, black, and light white	The coat is predominantly uniform and greenish, with an Aloe vera-like hue. Light grey
Colour pattern	Different	Different	Different	Uniform
Hair type	Ugly, straight	Glossy, straight	Glossy, straight	Glossy, straight
Hair length	Medium (1–2 mm) to long (>2 mm)	Medium (1–2 mm)	Medium (1–2 mm)	Medium (1–2 mm)
Hump size	Small, medium	Large	Medium	Small, medium
Hump location	Mid-back	Mid-back	Mid-back	Mid-back
Hump orientation	Upright	Upright	Slightly backward-leaning	Slightly backward-leaning
Udder size	Large	Medium	Small	Small
Teat size	Large	Medium	Small	Small

(58.25 ± 1.91 cm), the largest thoracic girth (200.38 ± 24.60 cm), and the highest estimated mean body weight (363.25 ± 51.13 kg), although not all pairwise body-weight contrasts reached statistical significance. The overall ecotype effect for height at withers was not statistically significant within this cohort (Table 3).

Morphometric analysis of males aged 12–15 years

In the older male cohort, phenotypic differentiation among ecotypes remained pronounced (Table 4). Aiden males maintained the highest estimated mean body weight (500.88 ± 38.14 kg), whereas Sifdacar males exhibited the lowest (361.80 ± 48.24 kg). Despite their lower body mass, Sifdacar males retained distinctive skeletal frame features, including the widest interorbital distance (34.00 ± 2.26 cm) and prominent hump-related dimensions. Significant ecotype effects were observed for facial length, interorbital distance, neck length, shoulder width, height at withers, height at hump, hump length, hump circumference, posterior limb length, tail length, foot pad circumference, and body weight (Table 4). These data suggest that conformation differences persist into maturity, though age-related growth trajectories may vary by ecotype.

Morphometric analysis of females aged 12–15 years

Older females also displayed distinct phenotypic variation across ecotypes (Table 5). Aiden females again exhibited the highest estimated mean body weight (490.42 ± 11.66 kg), whereas Sifdacar females displayed the greatest shoulder width (232.75 ± 13.80 cm) and among the longest facial measurements (57.38 ±

1.08 cm). Significant ecotypic differences were preserved for facial length, interorbital distance, shoulder width, height at hump, body length, tail length, and foot pad circumference (Table 5). Conversely, height at withers, thoracic girth, abdominal circumference, and body weight did not differ significantly among ecotypes in this mature age class, indicating a partial convergence of structural size traits in aging females (Table 5).

Milk production performance

Reported daily milk offtake did not differ significantly among the evaluated ecotypes ($P = 0.814$; Table 6). The Hoor ecotype exhibited the highest numerical mean (7.70 ± 2.47 L/day), followed by Aiden (7.34 ± 2.46 L/day), Sifdacar (7.25 ± 2.29 L/day), and Gellab (7.24 ± 2.08 L/day). The ranges of observed daily milk offtake overlapped across groups, with Hoor displaying the widest distribution (5–13 L/day) (Table 7). These numerical differences should therefore be interpreted descriptively rather than as evidence of ecotype-level milk-production differences.

Exploratory multivariate morphometric analysis

Exploratory principal component analysis (PCA) based on standardised morphometric traits showed partial multivariate separation among ecotypes, with substantial overlap at the individual-animal level (Figure 4). The first two principal components accounted for 31.6% of the total standardised variance, with PC1 and PC2 explaining 18.1% and 13.5%, respectively. PC1 was primarily loaded by hump circumference, height at withers, hump height, ear length, and tail length, whereas PC2 was predominantly associated with estimated body weight,

TABLE 2 Mean body weight and linear body measurements of Somali camel bulls aged 8–11 years by ecotype*.

Quantitative trait	Aiden (mean $\pm$ SEM)	Gellab (mean $\pm$ SEM)	Hoor (mean $\pm$ SEM)	Sifdacar (mean $\pm$ SEM)	P-value
N	24	20	20	24	
FL (cm)	49.0 $\pm$ 2.26 ^b	46.4 $\pm$ 2.47 ^b	45.8 $\pm$ 2.47 ^b	57.0 $\pm$ 2.26 ^a	0.001
DE (cm)	23.17 $\pm$ 1.82 ^a	22.6 $\pm$ 2.00 ^a	22.8 $\pm$ 2.00 ^a	27.0 $\pm$ 1.82 ^a	0.015
EL (cm)	12.0 $\pm$ 0.84 ^a	13.4 $\pm$ 0.92 ^a	12.8 $\pm$ 0.92 ^a	12.83 $\pm$ 0.84 ^a	0.276
NL (cm)	110.55 $\pm$ 9.71 ^b	128.6 $\pm$ 10.63 ^{ab}	56.8 $\pm$ 10.63 ^c	146.83 $\pm$ 9.71 ^a	0.003
WS (cm)	190.83 $\pm$ 12.51 ^a	180.2 $\pm$ 13.71 ^a	136.8 $\pm$ 13.71 ^b	216.67 $\pm$ 12.51 ^a	0.002
HW (cm)	98.83 $\pm$ 7.44 ^b	96.2 $\pm$ 8.14 ^b	95.8 $\pm$ 8.14 ^b	161.0 $\pm$ 7.44 ^a	0.000
TG (cm)	157.83 $\pm$ 10.51 ^a	193.0 $\pm$ 11.51 ^a	184.0 $\pm$ 11.51 ^a	178.17 $\pm$ 10.51 ^a	0.145
ALL (cm)	164.5 $\pm$ 7.97 ^a	137.0 $\pm$ 8.73 ^b	142.2 $\pm$ 8.73 ^{ab}	155.5 $\pm$ 7.97 ^{ab}	0.038
HH (cm)	121.5 $\pm$ 4.73 ^c	96.2 $\pm$ 5.19 ^d	140.2 $\pm$ 5.19 ^b	209.33 $\pm$ 4.73 ^a	0.010
AC (cm)	201.67 $\pm$ 10.12 ^b	242.0 $\pm$ 11.09 ^a	159.0 $\pm$ 11.09 ^c	162.33 $\pm$ 10.12 ^c	0.061
HI (cm)	62.83 $\pm$ 15.13 ^a	65.2 $\pm$ 16.58 ^a	81.8 $\pm$ 16.58 ^a	62.17 $\pm$ 15.13 ^a	0.054
Hh (cm)	52.33 $\pm$ 4.30 ^a	49.2 $\pm$ 4.71 ^a	51.0 $\pm$ 4.71 ^a	43.0 $\pm$ 4.30 ^a	0.128
Hc (cm)	29.05 $\pm$ 14.88 ^b	21.18 $\pm$ 16.30 ^b	36.4 $\pm$ 16.30 ^b	85.17 $\pm$ 14.88 ^a	0.039
BL (cm)	148.0 $\pm$ 9.78 ^a	161.2 $\pm$ 10.71 ^a	137.0 $\pm$ 10.71 ^a	137.83 $\pm$ 9.78 ^a	0.079
PLL (cm)	107.67 $\pm$ 13.58 ^b	175.0 $\pm$ 14.87 ^a	126.4 $\pm$ 14.87 ^b	132.67 $\pm$ 13.58 ^b	0.002
TL (cm)	63.33 $\pm$ 2.98 ^a	47.2 $\pm$ 3.26 ^b	50.6 $\pm$ 3.26 ^b	54.33 $\pm$ 2.98 ^{ab}	0.015
FPC (cm)	23.5 $\pm$ 0.69 ^a	19.2 $\pm$ 0.75 ^b	21.6 $\pm$ 0.75 ^a	22.67 $\pm$ 0.69 ^a	0.046
BW (kg)	430 $\pm$ 30.2 ^a	390.0 $\pm$ 33.08 ^a	353.2 $\pm$ 33.08 ^b	264.33 $\pm$ 30.2 ^b	0.001

*Within each row, means with different superscript letters are significantly different ($P < 0.05$), whereas means sharing the same letter are not significantly different ($P > 0.05$); the numerical values indicate the direction and magnitude of the difference. FL, Face length; DE, Distance between the eyes; EL, Ear length; NL, Neck length; WS, Width at shoulders; HW, Height at withers; ALL, Anterior limb length; TG, Thoracic girth; HH, Height at hump; HI, Hump length; Hc, Hump circumference; Hh, Hump height; BL, Body length; AC, Abdomen circumference; PLL, Posterior limb length; FPC, Foot pad circumference; TL, Tail length, and BW, Body weight.

thoracic girth, facial length, posterior limb length, and height at hump. Linear discriminant analysis (LDA) with five-fold cross-validation achieved 54.2% classification accuracy. In addition, k -means clustering ($k = 4$) showed weak alignment with the designated pastoral ecotype labels.

Discussion

Morphological differentiation and ecotype identity

This study provides quantitative evidence that locally recognised Somali dromedary camel ecotypes are associated with measurable phenotypic variation under pastoral field conditions. Across both sexes and multiple age cohorts, The Hoor, Aiden, Gellab, and Sifdacar ecotypes exhibited distinct structural conformations, skeletal frames, and qualitative attributes. These findings indicate that traditional pastoral classification systems reflect genuine biophysical variation rather than arbitrary nomenclature. This position aligns with broader camel characterisation literature, which consistently demonstrates that regional or pastoral types can be reliably differentiated using linear body measurements and external

morphology (FAO, 2008; Yosef et al., 2014; Legesse et al., 2018; Tandoh et al., 2018; Ehsaninia et al., 2020; Yakubu et al., 2022; Akhmetsadykova et al., 2023).

The morphometric profiles identified herein indicate measurable differences in conformation among pastoral types. The Aiden ecotype generally exhibited the highest estimated body mass, particularly in older mature cohorts, which is consistent with pastoral descriptions of a robust, multipurpose animal. Conversely, Sifdacar camels showed a taller, more elongated skeletal frame across several comparisons (notably among younger males), while the Gellab ecotype often showed more pronounced thoracic and shoulder measurements. Although the Hoor ecotype displayed less extreme skeletal dimensions, it was qualitatively associated with larger udder and teat dimensions in this field assessment. These mammary observations should be interpreted as descriptive traits and not as evidence of intrinsic dairy superiority. The ecotypic differences in milk yield were statistically non-significant, and baseline data regarding milk yield was based on owner reports. Parallel intra-country variations have been documented in Sudanese, Ethiopian, Nigerian, and Iranian camel populations, where ecotypes vary not only in absolute size but also in structural proportions. Such morphometric variation may be associated with traits relevant to

TABLE 3 Mean body weight and linear body measurements of Somali camel cows aged 8–11 years by ecotype*.

Quantitative trait	Aiden (mean $\pm$ SEM)	Gellab (mean $\pm$ SEM)	Hoor (mean $\pm$ SEM)	Sifdacar (mean $\pm$ SEM)	P-value
N	32	28	32	24	
FL (cm)	58.25 $\pm$ 1.91 ^a	57.43 $\pm$ 1.41 ^{ab}	53.38 $\pm$ 0.75 ^b	54.83 $\pm$ 1.28 ^{ab}	0.069
DE (cm)	23.25 $\pm$ 0.73 ^a	21.14 $\pm$ 0.34 ^{ab}	22.38 $\pm$ 0.82 ^b	22.33 $\pm$ 0.42 ^{ab}	0.175
EL (cm)	11.88 $\pm$ 0.40 ^a	11.14 $\pm$ 0.14 ^{ab}	12.62 $\pm$ 1.13 ^b	10.83 $\pm$ 1.66 ^{ab}	0.562
NL (cm)	99.25 $\pm$ 2.54 ^a	104.14 $\pm$ 0.70 ^{ab}	104.38 $\pm$ 2.51 ^b	100.50 $\pm$ 3.91 ^{ab}	0.387
WS (cm)	188.75 $\pm$ 12.25 ^a	198.71 $\pm$ 2.75 ^{ab}	169.88 $\pm$ 14.80 ^b	194.67 $\pm$ 2.12 ^{ab}	0.251
HW (cm)	85.50 $\pm$ 6.48 ^a	146.50 $\pm$ 48.50 ^a	138.62 $\pm$ 17.54 ^a	115.33 $\pm$ 34.72 ^a	0.103
TG (cm)	200.38 $\pm$ 24.60 ^a	162.14 $\pm$ 8.08 ^{ab}	193.88 $\pm$ 16.34 ^b	171.50 $\pm$ 19.05 ^{ab}	0.427
ALL (cm)	152.38 $\pm$ 6.38 ^a	155.86 $\pm$ 2.14 ^{ab}	140.75 $\pm$ 4.20 ^b	135.67 $\pm$ 3.17 ^{ab}	0.017
HH (cm)	193.62 $\pm$ 15.09 ^a	200.71 $\pm$ 2.88 ^{ab}	163.88 $\pm$ 22.85 ^b	212.00 $\pm$ 3.01 ^{ab}	0.171
AC (cm)	184.25 $\pm$ 7.32 ^a	190.29 $\pm$ 1.67 ^{ab}	188.12 $\pm$ 7.72 ^b	184.67 $\pm$ 15.62 ^{ab}	0.955
HI (cm)	34.12 $\pm$ 7.58 ^a	23.00 $\pm$ 0.85 ^{ab}	87.75 $\pm$ 31.66 ^b	49.83 $\pm$ 28.26 ^{ab}	0.164
Hh (cm)	47.62 $\pm$ 6.03 ^a	40.57 $\pm$ 1.27 ^{ab}	41.62 $\pm$ 1.83 ^b	34.50 $\pm$ 2.01 ^{ab}	0.129
Hc (cm)	53.75 $\pm$ 5.79 ^a	47.71 $\pm$ 1.29 ^{ab}	100.62 $\pm$ 25.79 ^b	61.67 $\pm$ 25.35 ^{ab}	0.158
BL (cm)	169.62 $\pm$ 7.67 ^a	149.86 $\pm$ 1.86 ^{ab}	140.25 $\pm$ 12.68 ^b	139.50 $\pm$ 15.18 ^{ab}	0.150
PLL (cm)	171.38 $\pm$ 4.27 ^a	149.43 $\pm$ 16.57 ^{ab}	154.25 $\pm$ 4.62 ^b	72.67 $\pm$ 16.49 ^{ab}	0.000
TL (cm)	64.38 $\pm$ 12.85 ^a	61.00 $\pm$ 2.00 ^{ab}	45.00 $\pm$ 4.59 ^b	47.50 $\pm$ 4.67 ^{ab}	0.227
FPC (cm)	23.00 $\pm$ 1.22 ^a	21.14 $\pm$ 0.14 ^{ab}	19.88 $\pm$ 0.88 ^b	24.83 $\pm$ 3.32 ^{ab}	0.179
BW (kg)	363.25 $\pm$ 51.13 ^a	306.57 $\pm$ 14.92 ^{ab}	328.38 $\pm$ 49.19 ^b	299.33 $\pm$ 26.54 ^{ab}	0.698

*Within each row, means with different superscript letters are significantly different ($P < 0.05$), whereas means sharing the same letter are not significantly different ($P > 0.05$); the numerical values indicate the direction and magnitude of the difference. FL, Face length; DE, Distance between the eyes; EL, Ear length; NL, Neck length; WS, Width at shoulders; HW, Height at withers; ALL, Anterior limb length; TG, Thoracic girth; HH, Height at hump; HI, Hump length; Hc, Hump circumference; Hh, Hump height; BL, Body length; AC, Abdomen circumference; PLL, Posterior limb length; FPC, Foot pad circumference; TL, Tail length, and BW, Body weight.

environmental stress tolerance, foraging range, thermodynamic endurance, consumer market preferences, and production orientation (Ishag et al., 2010; Ishag and Ahmed, 2011; Tandoh et al., 2018; Bekele et al., 2018; Ehsaninia et al., 2020; Alaqeely et al., 2021).

The exploratory multivariate outcomes refined the interpretation of the univariate analyses. The PCA indicated that these ecotypes occupy partially distinct regions of morphometric space, primarily segregated by axes associated with skeletal frame, hump dimensions, and body mass. However, the substantial individual-level overlap confirms that a single multivariate technique cannot justify strict breed-level categorisation. This pattern is consistent with mobile pastoral systems, where herd movement, routine sire exchange, and environmental variation may maintain phenotypic continuity while preserving recognisable local ecotypic profiles. Nonetheless, the cross-sectional field design of this study means that production environment and management confounding cannot be entirely ruled out. Apparent ecotype differences in both body measurements and reported milk offtake should therefore be interpreted cautiously, because unmeasured region, forage availability, water access, herd management, and micro-environmental conditions may have contributed to the observed

patterns. Foraging regimes, mobility dynamics, disease burdens, reproductive states, seasonal body condition scores (BCS), and micro-ecological variations may influence linear dimensions and soft-tissue traits.

Adaptive significance under pastoral production systems

From a pastoral systems perspective, these morphometric variations may represent biologically and culturally meaningful diversity. Within highly erratic dryland ecosystems, herd diversification constitutes a foundational livelihood strategy; pastoralists select and value specific animals based on prioritised functions such as milk yields, mobility, drought resilience, body fat reserves, reproductive efficiency, or commercial market value. Therefore, the maintenance of distinct ecotypes may reflect a localised strategy of animal management shaped by ecological pressures, selection objectives, and cultural preferences, rather than a mere taxonomic anomaly (Bulliet, 1990; Herrero et al., 2016; Mirkena et al., 2018; Burger et al., 2019; Faye, 2020; Köhler-Rollefson, 2022). For Somalia, where severe climate volatility and rangeland degradation remain primary constraints, documenting this phenotypic diversity is important for resilience-

TABLE 4 Mean body weight and linear body measurements of camel bulls aged 12–15 years by ecotype*.

Quantitative trait	Aiden (mean $\pm$ SEM)	Gellab (mean $\pm$ SEM)	Hoor (mean $\pm$ SEM)	Sifdacar (mean $\pm$ SEM)	P-value
N	32	24	24	20	
FL (cm)	51.13 $\pm$ 1.71 ^a	54.00 $\pm$ 1.97 ^a	52.67 $\pm$ 1.97 ^a	45.20 $\pm$ 2.16 ^b	0.011
DE (cm)	24.38 $\pm$ 1.78 ^b	26.00 $\pm$ 2.06 ^b	23.67 $\pm$ 2.06 ^b	34.00 $\pm$ 2.26 ^a	0.019
EL (cm)	12.75 $\pm$ 0.32 ^a	13.33 $\pm$ 0.37 ^a	12.50 $\pm$ 0.37 ^a	12.40 $\pm$ 0.41 ^a	0.733
NL (cm)	115.23 $\pm$ 6.41 ^a	97.83 $\pm$ 7.40 ^a	105.23 $\pm$ 7.40 ^a	55.60 $\pm$ 8.11 ^b	0.000
WS (cm)	198.13 $\pm$ 4.62 ^a	199.83 $\pm$ 5.33 ^a	183.67 $\pm$ 5.33 ^{ab}	168.80 $\pm$ 5.84 ^b	0.004
HW (cm)	91.00 $\pm$ 5.06 ^a	68.33 $\pm$ 5.84 ^b	79.50 $\pm$ 5.84 ^{ab}	66.20 $\pm$ 6.40 ^b	0.001
TG (cm)	172.25 $\pm$ 9.87 ^a	187.50 $\pm$ 11.4 ^a	177.33 $\pm$ 11.4 ^a	138.60 $\pm$ 12.49 ^b	0.169
ALL (cm)	155.13 $\pm$ 6.01 ^a	157.33 $\pm$ 6.94 ^a	157.17 $\pm$ 6.94 ^a	145.20 $\pm$ 7.60 ^a	0.116
HH (cm)	178.00 $\pm$ 15.42 ^a	101.67 $\pm$ 17.80 ^b	137.00 $\pm$ 17.80 ^{ab}	114.60 $\pm$ 19.50 ^b	0.000
AC (cm)	214.63 $\pm$ 12.37 ^a	211.17 $\pm$ 14.28 ^a	218.17 $\pm$ 14.28 ^a	225.20 $\pm$ 15.64 ^a	0.100
HI (cm)	44.88 $\pm$ 10.02 ^b	72.67 $\pm$ 11.57 ^b	57.83 $\pm$ 11.57 ^b	140.00 $\pm$ 12.68 ^a	0.000
Hh (cm)	65.88 $\pm$ 6.22 ^a	62.50 $\pm$ 7.19 ^a	56.17 $\pm$ 7.19 ^a	49.60 $\pm$ 7.87 ^a	0.458
Hc (cm)	27.78 $\pm$ 3.78 ^a	26.25 $\pm$ 4.36 ^a	27.17 $\pm$ 4.36 ^a	36.80 $\pm$ 4.78 ^a	0.033
BL (cm)	151.13 $\pm$ 5.89 ^a	151.17 $\pm$ 6.80 ^a	144.33 $\pm$ 6.80 ^a	139.60 $\pm$ 7.45 ^a	0.355
PLL (cm)	143.13 $\pm$ 9.46 ^a	169.33 $\pm$ 10.93 ^a	154.33 $\pm$ 10.93 ^a	154.80 $\pm$ 11.97 ^a	0.027
TL (cm)	64.50 $\pm$ 5.20 ^a	75.17 $\pm$ 6.00 ^a	74.67 $\pm$ 6.00 ^a	46.40 $\pm$ 6.58 ^b	0.010
FPC (cm)	18.88 $\pm$ 1.06 ^b	19.50 $\pm$ 1.23 ^b	20.50 $\pm$ 1.23 ^b	17.00 $\pm$ 1.34 ^a	0.003
BW (kg)	500.88 $\pm$ 38.14 ^a	463.33 $\pm$ 44.03 ^a	393.67 $\pm$ 44.03 ^a	361.80 $\pm$ 48.24 ^b	0.002

*Means with different superscripts are significantly different ($P < 0.05$), whereas means with the same superscript are not significantly different ($P > 0.05$). FL, Face length; DE, Distance between the eyes; EL, Ear length; NL, Neck length; WS, Width at shoulders; HW, Height at withers; ALL, Anterior limb length; TG, Thoracic girth; HH, Height at hump; HI, Hump length; Hc, Hump circumference; Hh, Hump height; BL, Body length; AC, Abdomen circumference; PLL, Posterior limb length; FPC, Foot pad circumference; TL, Tail length; and BW, Body weight.

oriented pastoralist community development and animal genetic resource (AnGR) conservation.

Milk yield variation and production relevance

Despite clear morphometric divergence, reported daily milk offtake varied minimally among the four ecotypes. The mean daily offtake recorded here (7.2–7.7 L/day) aligns with performance ranges reported for dromedaries managed under extensive pastoral or semi-intensive systems across the Horn of Africa (Bekele et al., 2002; Farah et al., 2007; Abdalla et al., 2015; Gebremichael et al., 2019; Zarrin et al., 2020). However, direct cross-study comparisons should be approached cautiously, as definitions vary regarding extracted volume, saleable yield, and total biological production. Although the Hoor ecotype had the highest numerical mean, this pattern should be interpreted only as a descriptive trend that is directionally consistent with pastoral perception, not as evidence of intrinsic milk-production capacity. The wide overlap among individuals and the non-significant ecotype effect indicate that this dataset cannot establish ecotype-level dairy superiority. Given that these data relied on herder recall, were cross-sectional, and lacked statistical adjustments for parity, lactation stage, calf suckling interventions, seasonality, nutrition, watering intervals, and herd-level management, they must be

treated as field estimations of reported offtake rather than definitive evaluations of intrinsic genetic potential.

These results are best interpreted as hypothesis-generating: under extensive conditions, environmental and management variation may obscure subtle ecotype-related differences in reported offtake. Dromedary milk offtake may be associated with seasonal forage availability, hydration intervals, parity, reproductive cycles, calf management, and overall herd health (Ismail, 1987; Al Haj and Al Kanhal, 2010; Nagy and Juhasz, 2016; Ali et al., 2018; Ainani et al., 2022; Nagy et al., 2022). Consequently, any apparent ecotype-related dairy tendency in this cross-sectional dataset should be interpreted cautiously, because immediate environmental factors and husbandry practices may be more influential than ecotypic classification alone. These findings suggest that any future genetic improvement initiative should be coupled with optimised animal husbandry, veterinary interventions, and longitudinal direct milk recording before drawing conclusions about ecotype-specific dairy potential.

Breeding, genetic resource management, and conservation priorities

The results address an important paradigm in contemporary camel science: distinct phenotypic differentiation does not

TABLE 5 Mean body weight and linear body measurements of camel cows aged 12–15 years by ecotype*.

Quantitative trait	Aiden (mean ± SEM)	Gellab (mean ± SEM)	Hoor (mean ± SEM)	Sifdacar (mean ± SEM)	P-value
N	48	40	48	32	
FL (cm)	56.08 ± 1.03 ^a	46.80 ± 0.25 ^b	56.58 ± 1.84 ^a	57.38 ± 1.08 ^a	0.000
DE (cm)	25.00 ± 0.65 ^a	19.90 ± 0.31 ^c	23.17 ± 0.47 ^b	22.50 ± 0.33 ^b	0.000
EL (cm)	13.17 ± 0.47 ^a	11.70 ± 0.21 ^a	12.50 ± 0.62 ^a	12.38 ± 1.02 ^a	0.381
NL (cm)	100.58 ± 8.24 ^a	100.70 ± 0.21 ^a	98.92 ± 2.74 ^a	101.75 ± 2.64 ^a	0.984
WS (cm)	201.42 ± 1.75 ^{bc}	220.90 ± 6.12 ^{ab}	182.00 ± 7.59 ^c	232.75 ± 13.80 ^a	0.000
HW (cm)	97.25 ± 3.86 ^a	95.70 ± 0.21 ^a	124.00 ± 13.73 ^a	119.75 ± 14.98 ^a	0.097
TG (cm)	187.58 ± 3.64 ^a	193.80 ± 0.74 ^a	192.00 ± 13.03 ^a	188.25 ± 10.56 ^a	0.950
ALL (cm)	144.75 ± 2.19 ^a	156.70 ± 0.21 ^a	148.08 ± 7.40 ^a	146.62 ± 10.39 ^a	0.509
HH (cm)	212.75 ± 2.65 ^a	218.70 ± 0.21 ^a	192.42 ± 10.50 ^b	210.38 ± 5.53 ^{ab}	0.033
AC (cm)	173.75 ± 3.11 ^a	183.40 ± 1.82 ^a	200.33 ± 14.99 ^a	172.38 ± 3.22 ^a	0.104
HI (cm)	52.17 ± 6.57 ^a	20.10 ± 0.10 ^a	67.00 ± 21.79 ^a	46.00 ± 20.76 ^a	0.185
Hh (cm)	46.50 ± 2.71 ^a	42.50 ± 0.17 ^{ab}	42.25 ± 2.26 ^{ab}	38.00 ± 1.05 ^b	0.065
Hc (cm)	56.42 ± 3.87 ^a	53.70 ± 0.21 ^a	88.67 ± 17.33 ^a	75.50 ± 21.11 ^a	0.173
BL (cm)	202.25 ± 8.25 ^a	217.60 ± 5.96 ^a	158.92 ± 3.46 ^b	143.88 ± 12.63 ^b	0.000
PLL (cm)	169.42 ± 2.65 ^a	173.20 ± 0.39 ^a	156.83 ± 3.04 ^{ab}	145.25 ± 19.25 ^b	0.076
TL (cm)	59.75 ± 2.03 ^a	52.60 ± 0.16 ^{ab}	49.00 ± 2.59 ^b	50.38 ± 4.52 ^b	0.016
FPC (cm)	20.17 ± 0.60 ^b	20.30 ± 0.30 ^b	20.83 ± 0.79 ^b	24.75 ± 2.35 ^a	0.025
BW (kg)	490.42 ± 11.66 ^a	467.00 ± 15.60 ^a	444.50 ± 42.73 ^a	382.50 ± 42.91 ^a	0.426

*Means with different superscripts are significantly different ($P < 0.05$), whereas means with the same superscript are not significantly different ($P > 0.05$). FL, Face length; DE, Distance between the eyes; EL, Ear length; NL, Neck length; WS, Width at shoulders; HW, Height at withers; ALL, Anterior limb length; TG, Thoracic girth; HH, Height at hump; HI, Hump length; Hc, Hump circumference; Hh, Hump height; BL, Body length; AC, Abdomen circumference; PLL, Posterior limb length; FPC, Foot pad circumference; TL, Tail length; and BW, Body weight.

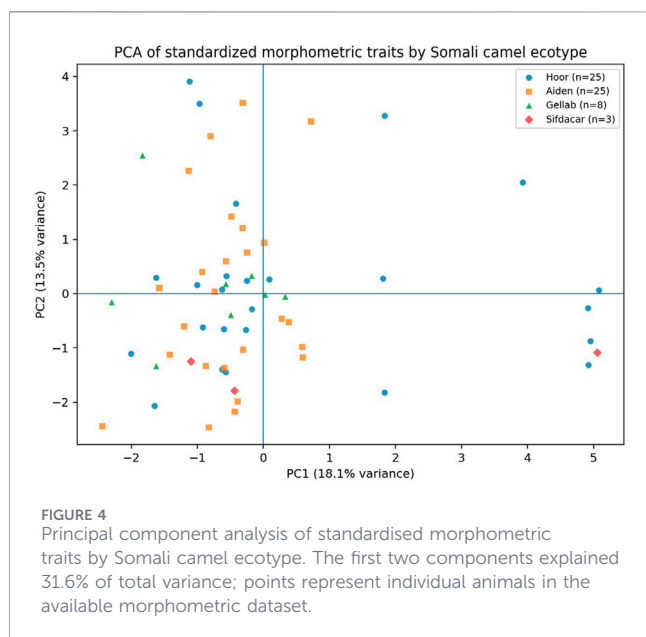
TABLE 6 Analysis of variance for milk production across Somali camel ecotypes.

Source of variation	Degrees of freedom (Df)	Sum of squares (sum Sq)	Mean square (mean Sq)	F-value	P-value
Ecotype	3	5.3	1.754	0.315	0.814
Residuals	124	690.1	5.565		

TABLE 7 Summary statistics of daily milk production across Somali camel ecotypes (n = 32 per ecotype; total n = 128).

Ecotype	Mean (L/day)	Standard deviation (L/day)	Minimum (L/day)	Maximum (L/day)	Range (L/day)
Aiden	7.34	2.46	4	11	8
Gellab	7.24	2.08	4	10	7
Hoor	7.70	2.47	5	13	10
Sifdacar	7.25	2.29	3	8	8

automatically imply isolated genetic lineages or closed breed boundaries. Genomic evaluations of East and North African dromedaries demonstrate that pastoralist-defined breeds or ecotypes can be morphometrically distinct while maintaining high intra-population genetic diversity and evidence of historical admixture, a direct consequence of historical mobility, herd mixing, and collective grazing boundaries (Bahbahani et al., 2019; Legesse et al., 2018; Piro et al., 2020; Piro, 2021; Alaqueely et al., 2021; Bagiyal et al., 2024). Therefore, our data underscore that Somali camels are phenotypically differentiated pastoral types rather than strictly



isolated genetic populations. Integrating baseline morphometrics with molecular markers remains the logical next step. To date, publicly available, Somali-specific genomic datasets capable of resolving these ecotypes remain unexploited, and molecular validation is still required. These findings have direct implications for national breeding and livestock conservation policies: (1) Somali camels should not be managed as a single, undifferentiated population in regional agricultural planning. (2) Ecotype-aware breeding strategies must carefully balance selection for economic traits (e.g., body mass or milk) with the preservation of adaptive fitness and genetic diversity under climate stressors. (3) Genetic improvement initiatives must remain grounded in indigenous pastoral knowledge, as local communities serve as the primary long-term custodians of these specialised genetic resources (Berghof et al., 2019; Abri and Faye, 2019; Köhler-Rollefson, 2022; Yakubu et al., 2022; Bagiyal et al., 2024). In practice, this supports community-based breeding programs (CBBPs). A systematic nation-wide screening program could identify elite sires through progeny testing, particularly by assessing their daughters' performance, and use them to establish foundation stock for nuclear CBBPs. This will require a large-scale recording of milk production, reproduction and management parameters on participating herds. Future programs should prioritise reproductive soundness and herd-level multi-trait selection indices rather than focusing only on mature body size or presumed dairy ecotypes (Monaco, 2025).

Study limitations and future research priorities

Several limitations should be considered when interpreting these findings. First, the study was cross-sectional and field-based, with accessible herds sampled through pastoral networks rather than through a complete probabilistic regional census. Second, the study covered central and southern Somalia only; therefore, ecotypes and production environments from northern regions, including

Puntland and Somaliland, were not captured. Third, exact herd-level coordinates, altitude, rainfall, temperature, vegetation composition, forage availability, water access, and management variables were not consistently available for all sampled herds. These missing spatial, environmental, and management variables limit the ability to separate ecotype effects from regional, ecological, and herd-management effects and should be considered when interpreting both body measurements and reported milk offtake.

Fourth, live body weight was estimated using a barymetric equation rather than direct weighing, and the equation has not been specifically validated for all Somali camel ecotypes. Fifth, age estimation relied on combined owner/herder recall and dentition, which may be affected by nutrition, management, and animal history. Sixth, milk data were based on short-recall owner-reported offtake from local containers rather than independently weighed total biological production. Therefore, milk values may include recall, rounding, and container-related error and should not be interpreted as evidence of intrinsic milk-production capacity.

Finally, parity, lactation stage, pregnancy status, calf-management practices, watering frequency, and detailed health information were not consistently recorded, and mammary assessments were descriptive rather than standardized dairy-conformation scores. Future studies should therefore combine longitudinal, directly measured milk-production records with standardized phenotypic recording, repeated reproductive and management data, and molecular/genomic benchmarking. Digital phenotyping tools, including structured udder and dairy-conformation scorecards, calibrated imaging, photogrammetry, and three-dimensional scanning approaches, could improve repeatability and comparability of morphometric and udder traits (ICAR, 2018; Salau et al., 2017; Strickland et al., 2025). These tools should be implemented alongside genomic characterization to identify the most informative traits, define ecotypic boundaries more rigorously, and create the evidence base for genomic selection in Somali camel breeding programs.

Conclusion

Somali camel ecotypes show clear phenotypic differentiation, supporting traditional pastoral classifications through measurable differences in body conformation and external morphology under field conditions. Aiden camels generally had a heavier, more robust frame, Sifdacar showed a taller, more elongated build, and Hoor females showed descriptive mammary features that are consistent with pastoral perceptions of dairy orientation. However, these observations should not be interpreted as evidence of fixed genetic boundaries, structural superiority, or superior biological milk-production capacity. Under extensive pastoral management, reported daily milk offtake did not differ significantly among ecotypes.

Overall, ecotype identity is useful for documenting and conserving Somali camel diversity, but practical milk-production gains are likely to require improvements in nutrition, watering access, reproductive management, veterinary care, value-chain development, and longitudinal direct milk recording alongside community-based breeding. This study provides a useful morphometric baseline for pastoral livestock development,

community-based breeding programs, and the long-term conservation of Somali camel genetic resources.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical approval for this study was obtained from the Research Ethics Committee of the Faculty of Veterinary Medicine and Animal Husbandry, Somali National University, following a review of the study protocol, survey tools, and consent procedures (Approval No. SNU-FVM/2023/24). Informed verbal consent was obtained from participating herders before interview and animal assessment. All measurements were non-invasive and were performed with attention to animal welfare and minimal handling stress.

Author contributions

SM, DM, HH, and PT conceived and designed the study. SM, AS, AM, and AA conducted field data collection and data curation. SM, HF, AA, MK, and PT performed the data analysis and reviewed and edited the manuscript. SM prepared the first draft. DM, HH, HF, AA, and PT critically revised the manuscript for important intellectual content. All authors read and approved the final manuscript.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

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Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontierspartnerships.org/articles/10.3389/past.2026.16713/full#supplementary-material>

SUPPLEMENTARY FIGURE S1

Boxplot of daily milk production by Somali camel ecotype.

SUPPLEMENTARY FIGURE S2

Mean height at withers of bulls aged 8–11 years across Somali camel ecotypes.

SUPPLEMENTARY FIGURE S3

Mean body weight of bulls aged 8–11 years across Somali camel ecotypes.

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