Pastoralism
Research, Policy and Practice

TYPE Original Research
PUBLISHED 11 November 2026
DOI 10.3389/past.2026.17716

Check for updates

OPEN ACCESS

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RECEIVED 27 August 2026
REVISED 04 October 2026
ACCEPTED 23 October 2026
PUBLISHED 11 November 2026

CITATION
Ould Ahmed M, El Hadj Y, Mohamed El Alem M, El Mouhab EH, Hamady S, Hamrouni A, Sidaty Regad SB, Ould Mohamed Salem Boukhary A and Djemali M (2026) Economic performance and associated characteristics of gross margin in peri-urban dairy camel farms around Nouakchott, Mauritania. *Pastoralism* 16:17716. doi: 10.3389/past.2026.17716

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Economic performance and associated characteristics of gross margin in peri-urban dairy camel farms around Nouakchott, Mauritania

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Camel farming occupies a growing place in the Mauritanian pastoral economy. The profitability of camel milk production, particularly in peri-urban systems around major cities, remains poorly documented, despite the country's persistent dependence on dairy imports. This study aimed to assess the economic performance of peri-urban dairy camel farms and to identify the technical and socio-economic characteristics associated with their gross margin. Data were collected from 60 camel milk producer-traders distributed across four peri-urban roadside axes of Nouakchott; 59 farms with complete records were retained for analysis. These data were recorded using a semi-structured questionnaire (April-May 2024) and then analyzed by descriptive statistics, correlation analysis and standardized multiple linear regression. Results show that the farms generated an average annual gross margin of 355,588 MRU (~9,000 USD) per farmer, generated mainly by milk sales (65% of revenue) and constrained mainly by feed costs (73% of expenditure). Multiple regression showed that gross margin per lactating camel increased significantly with the proportion of milk marketed, lactation length and daily milk yield (adjusted R^2 = 0.20, p = 0.007), whereas herd size, camel type and farmers' education level had no significant effect on gross margin per animal, indicating that profitability per lactating camel was associated with milk collection and lactation management rather than with herd expansion; sensitivity analyses showed that herd size nonetheless remained significantly associated with total farm income, indicating that its irrelevance is specific to per-animal profitability rather than to farm income as a whole. These findings suggest that extension and investment programs targeting peri-urban dairy camel farming should prioritize

improving milk collection, market access and lactation management rather than herd-size growth, in order to strengthen the economic resilience of camel-farming households in Mauritania.

KEYWORDS

camel milk, gross margin analysis, Mauritania, multiple regression, peri-urban camel farming

Introduction

Livestock farming occupies a central place in the Mauritanian economy. It is a major source of income for rural and pastoral communities, contributes significantly to national food security and sovereignty, and represents substantial export potential. It accounted for 10.3% of GDP in 2024 and provides income to nearly 60% of the population (RAMO/SCAPP, 2025).

Given its socio-economic importance, the livestock sector has been identified as a priority area under the Accelerated Growth and Shared Prosperity Strategy (2016–2030). The sector plays a central role in achieving the Sustainable Development Goals (SDGs), particularly in pastoral areas, which are home to a large share of vulnerable populations. It contributes, directly or indirectly, to several SDGs: SDG 1, SDG 2, SDG 3, SDG 5, SDG 12, SDG 13 and SDG 17. Despite the size of the national ruminant herd, estimated at 29,339,913 head, including 13,915,459 sheep, 7,275,809 goats, 6,147,368 cattle and 2,001,277 camels (Agence Nationale de la Statistique et de l'Analyse Démographique et Economique, 2023), the country continues to import milk and dairy products. Indeed, in 2014, Mauritanian dairy imports accounted for 18% of the value of imported food products (FAOEuropean Union and CIRAD, 2023).

This gap is all the more striking given that the global camel milk industry is undergoing a phase of rapid expansion, supported by growing recognition of its nutritional and functional properties as well as rising demand in both traditional and emerging markets (Ait El Alia et al., 2025). Across the Sahel and sub-Saharan Africa more broadly, rapid urbanization and rising urban food demand have likewise favored the emergence of peri-urban livestock systems, which combine proximity to consumer markets with relatively low entry costs for producers (Ehui et al., 1996; Amadou et al., 2012). Camel farming in Mauritania is thus well positioned to benefit from these two dynamics, provided that the specific constraints of peri-urban camel farming are properly documented and taken into account.

This situation has led the Mauritanian government to implement policies aimed at intensifying national dairy production. To meet growing demand for animal protein, public authorities have paid particular attention to the livestock sector. Several incentives have been introduced, such as the creation of experimental farms and the promotion of dairy infrastructure (Magnani and Fall 2020). According to Ould Ahmed et al. (2024), the peri-urban system offers opportunities for camel-farming activities. This type of farming is particularly widespread on the outskirts of major Mauritanian cities, owing to growing demand for camel milk and other by-products. However, significant challenges remain, notably in terms of costs, production levels, marketing and sustainability.

Taken together, existing work on peri-urban and pastoral camel systems in the Sahel and the Horn of Africa (Farah et al., 2004; Faye et al., 2011; Noor et al., 2012; Mammeri et al., 2014; Babiker, 2014; Gebremichael et al., 2019; Mahamat Ahmat et al., 2023; 2024) has mainly documented production levels, cost structures and single-variable comparisons between income and expenditure, without formally testing which technical and socio-economic factors jointly explain differences in profitability between producers. To our knowledge, no study has applied a multivariate framework to identify the characteristics associated with gross margin in a peri-urban dairy camel farming system in the Sahel, nor tested whether these associations vary according to geographic location, breed or farmers' education level. This gap matters because it directly shapes the design of extension and investment programs: without knowing whether profitability is associated with herd size, animal productivity or commercial behavior, support policies risk targeting the wrong lever.

The objectives of this article were: (i) to assess the structure and magnitude of production costs associated with peri-urban camel farming, (ii) to analyses both the potential and actual income generated by the sale of camel milk and live animals, and to estimate profitability indicators enabling assessment of the economic viability of this farming system, and (iii) to identify key performance indicators to better understand the dynamics, development, challenges and opportunities of camel farming in systems increasingly integrated into urban and peri-urban environments.

These three objectives correspond, respectively, to the following three research questions that structure the analysis, framed here as explicit, testable hypotheses: (RQ1) What is the structure of production costs and revenue in the peri-urban dairy camel farming system of Nouakchott? (RQ2) Which technical factors (milk production, lactation length, milk collection) and socio-economic factors (herd size, breed, education, geographic zone) significantly explain variation in gross margin between farmers? (RQ3) Does profitability vary systematically according to peri-urban zone, camel type or farmers' education level, or is the system economically and technically homogeneous? We hypothesize that variables related to milk production and marketing, rather than herd size or fixed farmer characteristics, are the characteristics most strongly associated with profitability in this system.

To our knowledge, this study is among the first on peri-urban camel farming in the Sahel to combine descriptive statistics, rank correlations, non-parametric comparisons and standardized multiple regression within a single multi-method framework, allowing the relative contribution of production, marketing and socio-demographic characteristics to gross margin to be tested

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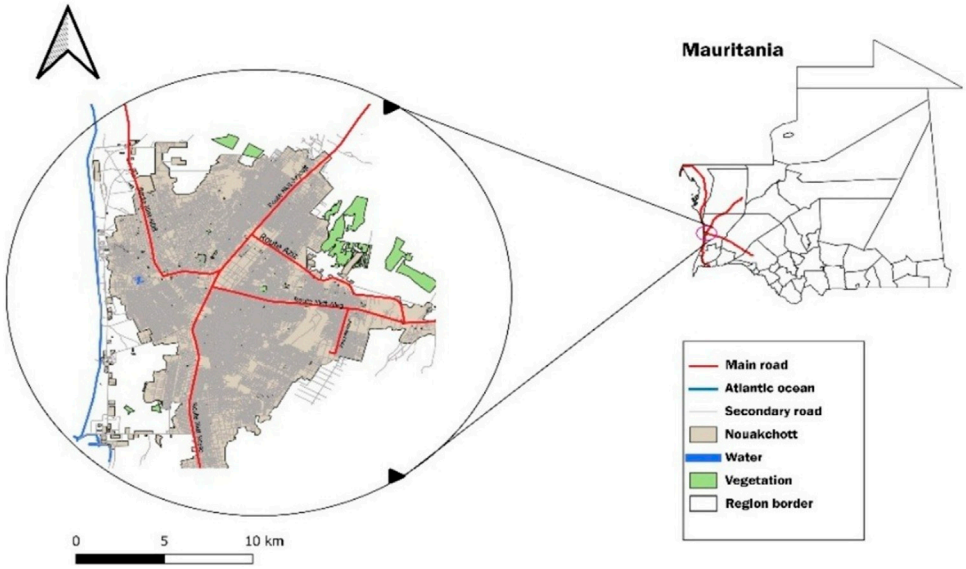


FIGURE 1
Geographical location of the study axes.



FIGURE 2
Peri-urban dairy camel herds in the city of Nouakchott.

explicitly rather than described separately, as detailed further in the Discussion.

Materials and methods

Geographical description of the study area

The survey was conducted in Nouakchott (18.0735° N; 15.9582° W), the capital of Mauritania (Figure 1). It targeted camel herders and dairy producers in the peri-urban areas of the city. The study area covers approximately 1,000 km^2 and lies in a desert zone close to the Atlantic Ocean, which strongly influences its climate and development. Nouakchott is the country's largest city, administratively divided into 3 regions (Nouakchott North, Nouakchott South and Nouakchott West), 9 districts (locally called Moughataa) and 9 communes, with an estimated population of 1,446,761, representing 29.4% of the total population.

Sampling method, data collection and statistical analysis

A purposive sampling technique was used to deliberately select dairy camel farms from the main peri-urban farming zones around Nouakchott, with the aim of covering the main production areas. Sites were defined *a priori* as the four main roadside axes leading out of the city, along which peri-urban dairy camel farms are concentrated (Akjoujt, Rosso, Aziz and Masoud), access to these roads largely shaping farmers' proximity to urban dairy markets. Within each axis, a list of known farms was compiled with the help of local extension agents, and farms were then selected in proportion to the approximate number of farms present on each axis, giving 21, 17, 11 and 10 farms on the Akjoujt, Rosso, Aziz and Masoud axes, respectively. The overall sample size (n = 60) was set according to the resources and time available for a single field campaign; it is comparable to that of other surveys on peri-urban camel farming conducted in the sub-region (generally 30 to 80 respondents; Babiker, 2014; Noor et al., 2012; Mammeri et al., 2014) and is treated here as a limitation of the study rather than as a basis for strong statistical generalization beyond the survey area.

Complete records of farms initially contacted but not ultimately included (for example because of refusal or unavailability) were not systematically kept by the field team for every axis, so an exhaustive participant-flow breakdown by axis cannot be reconstructed retrospectively; this is acknowledged here as a methodological limitation of the survey's documentation, in addition to its implications for generalization discussed in the Limitations section.

Data were collected in April–May 2024 through semi-structured, face-to-face interviews, conducted in a single visit per farm directly at the camps where the animals were kept (Figure 2), by trained enumerators speaking local languages. Lasting 30–60 min, these interviews combined spontaneous responses and direct questions to gather both objective information (technical, economic, accounting) and subjective information on farming practices, performance and production constraints, with a view to assessing the profitability of camel farms.

Data were entered using Microsoft Excel (Microsoft Office, 2019) and then cleaned to remove outliers and inconsistencies; of the 60 farms surveyed, one record had missing data for almost all technical and economic variables and had to be excluded, reducing the usable sample to 59 observations for all analyses. No other farm had missing values on the variables used in this study, so no imputation was required; implausible values (for example, a cost or revenue entry inconsistent with the corresponding physical quantity) were flagged during entry and cross-checked against the enumerator's paper record, with the farmer re-contacted by telephone where feasible to confirm the figure. Categorical variables were coded prior to analysis. Statistical processing was carried out using Python 3.12 (pandas 2.x, SciPy 1.11). The normality of the distribution of each quantitative variable was first checked using the Shapiro-Wilk test; as most production, cost and revenue variables departed significantly from normality ($p < 0.05$), non-parametric procedures (Spearman's rank correlation, Mann-Whitney U and Kruskal-Wallis H tests) were used to complement parametric tests (Pearson correlation, multiple linear regression by ordinary least squares on standardized variables) to identify the socio-economic and technical characteristics associated with gross margin. The significance threshold was set at $p < 0.05$ for all tests.

Because three of the significant predictors in the regression model (proportion of milk marketed, lactation length, daily milk yield) are technical or commercial variables that directly determine milk revenue, and milk revenue is itself one of the two components of gross margin (Equation 3), it is useful to make the accounting relationship between these quantities explicit before interpreting the regression results. Milk revenue is the product of daily milk yield, lactation length and milk price, multiplied by the proportion of that production that is marketed (Equations 1,2,); gross margin is milk revenue plus animal-sale revenue, minus total costs. Three of the six predictors entered in the regression (proportion of milk marketed, lactation length, daily milk yield) are therefore accounting antecedents of part of the outcome variable, rather than fully independent explanatory factors, and part of their statistical association with gross margin is mechanical by construction rather than necessarily behavioral. This does not invalidate the descriptive finding that these variables track gross margin closely, but it means the regression should be read as decomposing which components of the accounting identity vary most strongly with gross margin across farms, rather than as identifying causally independent drivers. Herd size and feed cost per head, by contrast, are not arithmetically embedded in the outcome and their non-significance cannot be explained by this mechanism.

The robustness of the multiple regression model was further assessed through residual diagnostics (Breusch-Pagan and White tests for heteroscedasticity, Cook's distance for influential observations) and heteroscedasticity-consistent (HC3) standard errors, and through three sensitivity specifications: a farm-level model using total gross margin, rather than gross margin per lactating camel, as the outcome, to test whether the ratio construction of the main outcome affected the results for herd size; a milk-only margin model excluding animal-sale revenue entirely, to test whether the results were sensitive to the inclusion of animal sales, which may partly reflect asset liquidation rather than recurring income; and a total farm revenue model, run in parallel with the main gross margin model, to make visible the marginal

TABLE 1 Sensitivity analyses: alternative regression specifications testing the robustness of the characteristics associated with gross margin to the outcome definition (n = 59 for all models).

Predictor	Farm-level gross margin	Milk-only margin per camel	Milk-only margin farm level	Total farm revenue
% milk sold	195,039 (0.005 **)	10,520 (<0.001 ***)	188,349 (0.001 **)	209,431 (0.006 **)
Lactation length	139,486 (0.036 *)	8,090 (<0.001 ***)	137,317 (0.002 **)	149,033 (0.048 *)
Daily milk yield	82,903 (0.123 ns)	6,129 (0.001 **)	118,504 (0.022 *)	89,416 (0.106 ns)
Feed cost per head	5,316 (0.825 ns)	−799 (0.211 ns)	−22,683 (0.168 ns)	19,954 (0.480 ns)
Farmer experience	54,893 (0.230 ns)	−489 (0.702 ns)	−1,992 (0.941 ns)	57,128 (0.267 ns)
Herd size	298,440 (0.010 *)	975 (0.340 ns)	−93,378 (0.201 ns)	884,256 (<0.001 ***)
Adjusted R^2	0.350	0.532	0.421	0.823
Heteroscedasticity (Breusch-Pagan p)	<0.001	0.061	<0.001	0.002

Coefficients (β, in MRU per SD of predictor) and significance are based on heteroscedasticity-robust (HC3) standard errors, given the presence of significant heteroscedasticity in most of these models (see row below); *p < 0.05, **p < 0.01, ***p < 0.001, ns = not significant.
Across all four alternative specifications, the proportion of milk marketed and lactation length remain significant, positively-signed predictors, whether the outcome is expressed per lactating camel or at farm level, and whether or not animal-sale revenue or costs are included indicating that these associations are not artefacts of the main-text model's ratio construction or of the treatment of animal sales. Herd size is a robust null result per lactating camel (columns 2–3), but becomes a significant positive predictor once the outcome is expressed at farm level (Farm-level gross margin and Total farm revenue columns), suggesting that farm size contributes to total farm income even though it does not explain differences in profitability per animal kept. Daily milk yield loses significance in the total-revenue specification once herd size is accounted for, suggesting that part of its association with gross margin in the main-text model reflects larger herds also tending to report higher yields. Significant heteroscedasticity was detected in three of the four models (Breusch-Pagan p < 0.01), for which the HC3 robust p-values reported here, rather than conventional OLS p-values, should be treated as the primary reference. Overall, sensitivity analyses showed that the observed associations were broadly consistent across alternative outcome specifications; this consistency is most clearly established for the farm-level and total-revenue models, whereas the milk-only margin specification, although informative, still shares the proportion of milk marketed with its own revenue component and should accordingly be read with that caveat in mind.

contribution of the management-related predictors independently of the cost side of the accounting identity described above. Full results are reported in Table 1.

Ethical considerations

This study relied exclusively on a voluntary socio-economic questionnaire administered to adult camel farmers and involved no experimental manipulation of animals. Before each interview, enumerators explained the purpose of the survey, and informed verbal consent was obtained from all respondents, who were free to decline participation or to not answer a question without any consequence. No nominal information was recorded in the database used for analysis, and all responses were anonymized prior to statistical processing. The survey protocol was reviewed and approved by the Research Ethics Committee of the École Supérieure Agronomique et Vétérinaire de Rosso (formerly Institut Supérieur d'Enseignement Technologique de Rosso), Mauritania (reference 2023/2024).

Calculation of the economic performance of camel farms

The economic performance of a dairy camel farm results from the gap between total expenditure incurred and revenue generated over the same financial year. It was assessed here using accounting data reported for 2023, for which all farmers surveyed had a sufficiently precise recollection of the monetary flows of their farms. Peri-urban camel farmers operate almost exclusively in the informal sector and do not keep recorded accounts; cost and revenue data were therefore reconstructed from their verbal declarations, collected through structured questions covering each expenditure item and each source of income. This declarative approach, although imperfect, remains the method most commonly used in the study of informal farming systems; recent work has nonetheless shown that it is exposed to a risk of systematic under-reporting, particularly for the largest herds and incomes (Abay et al., 2025). To limit this bias, enumerators cross-checked farmers' declarations, whenever possible, against a direct estimate of herd size and locally prevailing prices. The purpose of this section is to present the calculation approach used to obtain the most reliable possible estimate of the economic profitability of peri-urban dairy camel farms from the data thus available.

Costs associated with peri-urban dairy camel farming

Five expenditure items were identified from the field interviews, accounting for almost all the costs borne by peri-urban farms around Nouakchott: animal feed (purchase of concentrate feed on the local market, supplementing grazing), watering (water delivered by tanker truck or billed by the national water utility, SNDE), hired labor, veterinary care, and a residual 'other' category covering small equipment, transport and distribution. This breakdown by item allows not only the estimation of total production cost, but also the identification of the relative structure of expenditure, information directly usable to steer support policies (feed subsidies, labor support, etc.) towards the most constraining item, as shown by the results in Analysis of the economic costs associated with camel farming. Total annual cost (C) is given by Equation 1:

$$C_{Total} = C_{Feed} + C_{Labor} + C_{Watering} + C_{VetCare} + C_{Other} \quad (1)$$

$$C_{Feed} = \sum_{i=1}^{n=4} Feed_i \times Price_i$$

$$C_{Labour} = Number\ of\ workers \times Monthly\ wage \times 12$$

$$C_{Watering} = Mean\ daily\ watering\ cost\ per\ head \times Total\ number\ of\ camels \times 365$$

Revenue from peri-urban dairy camel farming

Peri-urban dairy camel farms derive the bulk of their monetary revenue from two sources: the sale of camel milk, collected daily and sold on Nouakchott's urban markets, and the sale of animals (weaned young, dry females, culled males), which is generally more occasional and more closely tied to household cash needs. Distinguishing between these two income sources, rather than using a single aggregate turnover figure, makes it possible to assess the degree of each farm's dependence on the dairy market — a central indicator for this study, developed further below. Total revenue (R) is calculated by Equation 2:

$$R_{Total} = R_{MilkSales} + R_{AnimalSales} \quad (2)$$

Calculation of socio-economic indicators for peri-urban dairy camel farming

Beyond the financial margin alone, the economic contribution of peri-urban camel farming was assessed through three complementary indicators: farm gross margin, the paid employment it generates, and the annual volume of animals sold. This combination of indicators, common in studies of livestock system performance in sub-Saharan Africa (Nkadimeng et al., 2021), makes it possible to move beyond a strictly accounting-based reading of profitability and capture the broader contribution of the activity to household livelihoods and the local economy.

Gross margin of peri-urban dairy camel farmers

The parameters calculated in Equations 1,2, allow the derivation of this study's central indicator, the gross margin (GM) of farms, which represents the balance available to remunerate the farmer's labor and any investments, once all monetary expenses have been covered (Equation 3). This indicator was calculated both at farm level (total annual gross margin) and per lactating camel (gross margin per head), enabling a comparison of profitability between farms of very different sizes a per-head normalization approach recommended in livestock gross margin analyses (Nkadimeng et al., 2021; Cervo et al., 2017) and used again in the regression model presented in the "Characteristics associated with economic performance: correlation and multivariate analysis" section. The gross margin formula is given by Equation 3:

Because the proportion of milk marketed is used as an explanatory variable in the regression presented in the "Characteristics associated with economic performance: correlation and multivariate analysis" section, its relationship to gross margin (the dependent variable) warrants explicit clarification. The proportion of milk marketed is defined as the volume of milk sold divided by the total volume of milk produced by the farm over the year (both measured in liters; the same production denominator underlying Table 2), and is therefore a physical quantity ratio rather than a monetary one. Milk retained for household consumption is not assigned a monetary value and is not included in farm revenue or in gross margin, which are constructed solely from the milk that was actually sold (Equation 2) net of the cost items in Equation 1. The proportion of milk marketed and gross margin are consequently related, selling a larger share of a given production raises milk revenue and, all else equal, gross margin, but they are not the same quantity or arithmetically equivalent, since gross margin also depends on milk price, output volume, animal sales and every cost item, none of which enter the marketed-share ratio. This relationship is discussed further, together with its implications for interpreting the regression results, in the Discussion.

TABLE 2 Camel milk production and marketing on peri-urban farms in Nouakchott.

Variable	Value
Mean total milk production (tonnes/farmer/year)	41.69 ± 34.52
Mean total milk sold (tonnes/farmer/year)	11.82 ± 8.06
Mean share of milk marketed (%)	32.83 ± 13.27
Mean camel milk price (MRU/litre)	64.50 ± 12.61
Mean total milk revenue (MRU/farmer/year)	759,828 ± 531,845

$$\boldsymbol{GM} = (\boldsymbol{R}_{MilkSales} + \boldsymbol{R}_{AnimalSales}) - \left(\boldsymbol{C}_{Feed} + \boldsymbol{C}_{Labor} + \boldsymbol{C}_{Watering} + \boldsymbol{C}_{VetCare} + \boldsymbol{C}_{Other}\right) \quad (3)$$

Employment creation on peri-urban dairy camel farms

Dairy camel farming is a relatively labor-intensive activity: feeding, twice-daily milking, collection, packaging and transport of milk to urban sale points require a regular human presence that few farms can provide on the basis of family labor alone. Paid employment creation was therefore retained as a fully-fledged indicator of the system's socio-economic performance, measured here by the number of permanent and seasonal workers remunerated by each farm, together with the corresponding annual wage bill. This indicator is of particular interest for a still-young value chain: recent interventions to structure the dairy camel value chain in the sub-region illustrate this sector's job-creation potential when supported by targeted investment in collection and processing — for example, an International Labor Organization program in Garissa County (Kenya) created 379 direct jobs, 326 of them held by women, around a camel milk collection and processing center (ILO, 2024). Although the institutional context differs from that of Nouakchott, this example illustrates the leverage that improved collection chains can exert on local employment a pathway taken up directly in this study's recommendations.

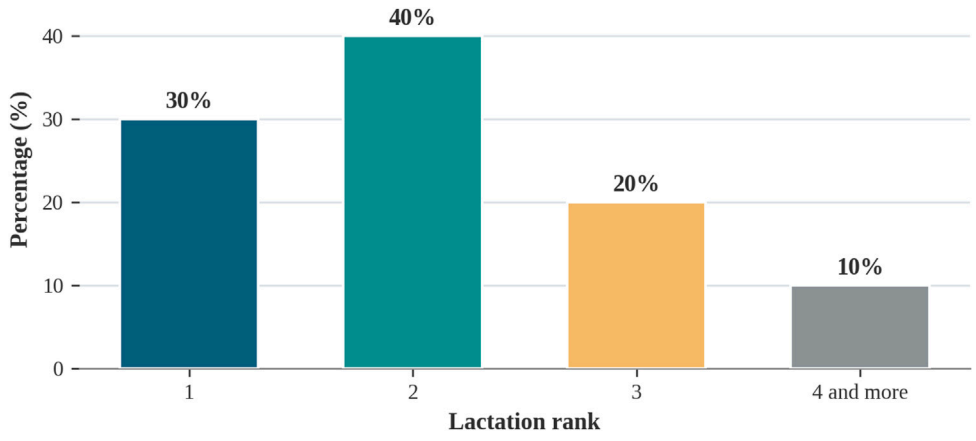


FIGURE 3
Distribution of dairy camels by lactation rank.

Volume of animals sold on peri-urban dairy camel farms

The volume of animals sold corresponds to the total number of head (weaned young, dry females, culled males) disposed of by each farm during the reference year. In a peri-urban system where milk sales account for only about a third of production on average (see Table 2), animal sales constitute a second source of liquidity that allows farmers to smooth their income between milk-collection campaigns and to cope with significant one-off expenses (input purchases, labor, etc.). This role of animal sales as a financial safety net in Sahelian peri-urban camel systems has been documented in Chad (Mahamat Ahmat et al., 2023) and more broadly in North Africa (Amsidder et al., 2024), where sales of live animals represent a growing share of the economic value generated by the camel value chain. Converting the volume of animals sold into monetary value thus makes it possible to assess the combined contribution of milk and animals to farmers' income and, more broadly, to the local and national economy.

All values are expressed in Mauritanian currency (MRU); they can be converted into US dollars using the average exchange rate published by the Central Bank of Mauritania (BCM, 2024) for the April–June 2024 data-collection period, i.e. 1 USD ≈ 39.50 MRU. This period was used for currency conversion because it corresponds to the timing of data collection, even though the underlying financial flows refer to the 2023 reference year (see "Calculation of the economic performance of camel farms"); as the ouguiya was broadly stable against the US dollar over this interval, the resulting USD approximations are not materially affected by this choice.

Results

The sample of farmers interviewed comprised the owners of 60 farms totaling 2,619 dairy camels. The average herd size per farmer was 44.38 ± 33.94 head, with a minimum of 12 and a maximum of 180 head. Results are presented following the order of the three research questions set out in the Introduction: the socio-demographic and technical characteristics of the farms precede the analysis of costs and revenue (RQ1), which is followed by the identification of the statistical characteristics associated with profitability (RQ2) and tests of homogeneity across zones, breeds and education levels (RQ3).

Socio-demographic aspects

Socio-demographic characteristics of study participants

All respondents in this survey were actively involved in the camel milk trade. The majority of the camel milk producers surveyed were married (78.33%). Farmers' age ranged from 19 to 84 years, with a mean of 47.95 ± 16.55 years, and household size ranged from 3 to 9 people, with a mean of 5.36 ± 1.32 people per farmer. Among respondents, 30.5% were illiterate; only 5.1% had received formal primary education, and the majority (64.4%) had received informal or religious (Koranic) education. Respondents' experience in the camel milk trade ranged from a few years to several decades. The majority of these peri-urban dairy camel farms (54.4%) had existed for more than 20 years. In addition, 17% of respondents had been engaged in this activity for 10–20 years, while 28.9% of farms had been established less than 10 years ago.

The activity remains overwhelmingly male: 96.6% of farmers surveyed were men, versus 3.4% women, an imbalance comparable to that reported in other West African peri-urban camel farming systems (Amadou et al., 2012) and reflecting the traditional division of roles in livestock management within Sahelian pastoral households, with women more frequently involved in milk processing and local marketing than in herd management.

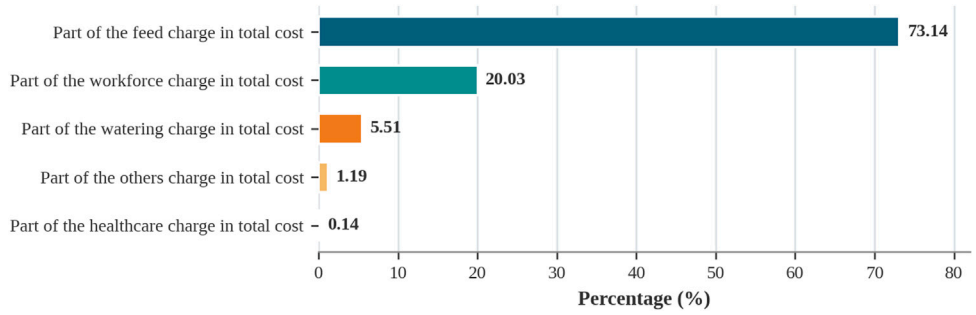


FIGURE 4
Distribution of costs on peri-urban farms.

General characterization of peri-urban dairy camel farms

Composition of the peri-urban dairy camel herd

Herd composition comprised 90% lactating camels at animal level, while at farm level only 10% of farmers surveyed reported keeping breeding males. Among lactating camels, the herd was made up on average of 30% first-lactation, 40% second-lactation, 20% third-lactation and 10% fourth-lactation-or-later animals (Figure 3). This demographic structure characterized by the near-total dominance of females and the scarcity of breeding males retained in the herd, reflects a farming system specialized in milk production rather than mixed milk-and-breeding management. The majority (89%) of farmers likely resort to off-farm mating or the purchase of sires rather than the permanent upkeep of a breeding male, whose annual maintenance cost is not offset by direct milk production.

The near-universal presence of lactating camels clearly indicates that these farms are oriented towards milk production and towards maintaining their reproductive potential.

Milking frequency, lactation length and milk production

The survey showed that milking is carried out in the presence of the calf. It is performed manually, following traditional practice, with the calf stimulating milk let-down by suckling the mother for a few minutes. The majority of farmers (80%) milk their camels twice a day, morning and evening. Farmers in the peri-urban dairy system are advised to increase milking frequency to three times a day. Studies have shown that tripling milking frequency can increase daily output by 28.5% (Kamoun, 1995). Lactation length among the farmers surveyed ranged from 6 to 18 months, with a mean of 12.22 ± 3.55 months. Daily milk yield ranged from 4 to 9 L per camel, with a mean of 5.18 ± 0.98 L per day, giving an average yield of approximately 1,900 L per lactation.

Production, marketing and value of camel milk sales

The production, marketing and sales-value parameters of camel milk are presented in Table 2.

The quantity of camel milk marketed remains relatively low compared with the quantity produced. Respondents indicated that milk price varies seasonally owing to fluctuations in supply. This production plays an important role in meeting market and consumer demand, given the strong cultural attachment to camel milk consumption. It should be noted that the most common form of consumption is raw milk, which requires short marketing channels.

What becomes of camels after lactation?

Results indicate that 17% of farmers choose to keep their camels in their pastoral or peri-urban herds after lactation. By contrast, 37.3% of farmers surveyed send their dairy camels to slaughter once lactation ends. It should be noted that this category consists mainly of traders rather than farmers in the strict sense. In addition, 45.7% of farmers choose to retain most females while selling some, depending on their needs and on the quality and age of the females. This practice of selling good milkers to butchers after lactation could lead to counter-selection, potentially excluding the best females from breeding. Of the 59 farms retained for statistical analysis, 32 reported a single, exclusive post-lactation practice (keeping, selling or sending to slaughter), while 27 combined several practices depending on the animal; a Mann-Whitney U test showed no significant difference in gross margin between these two groups (430,122 versus 267,250 MRU/year; $U = 345$, $p = 0.19$), nor in gross margin per lactating camel ($U = 372$, $p = 0.37$).

Technical and economic aspects

Characterization of camel farming performance and economic indicators

Analysis of the economic costs associated with camel farming

Camels play an important role in the economy of the study area. Assessing the costs and all expenditure items associated with peri-urban camel farming is essential for understanding economic activities and their relationship with local development. We identified five types of expenditure associated with peri-urban camel farming. To assess the whole of this expenditure, we represented the share of each in

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TABLE 3 Breakdown of costs by expenditure item.

Expenditure item	Total cost (MRU/year)	Mean ± SD (MRU/farmer/year)
Animal feed	37,555,200	636,528.81 ± 486,543.82
Labor	8,915,000	151,101.69 ± 80,796.18
Watering	2,828,520	47,941 ± 36,656.8
Veterinary care	54,200	934.48 ± 1011.95
Other	484,300	8,208.47 ± 3,229.51
Total costs	49,837,220	

Figure 4 for the farms studied as a whole. Feed costs represent the largest share, at 73.14% of total costs, followed by labor costs (20%) and watering costs (6%). These items (feed, labor, watering) are the highest because of the need for supplementary feed and the presence of permanent herders to manage the herds throughout the year.

Table 3 summarizes the different costs by expenditure item. A distinction was made between intermediate expenditure (feed and watering) and labor expenditure in order to determine the share of each type of expenditure in total camel-farming costs. Averaged across farms, approximately 80% of expenditure corresponded to intermediate expenditure (feed and watering combined), against approximately 20% to wage expenditure, the small remainder corresponding to veterinary care and other costs.

Analysis of revenue generated by peri-urban camel farming

The analysis of revenue generated by peri-urban camel farming is presented in Figure 5. According to the sample studied, 65.44% of revenue comes from milk sales, while 34.55% comes from the sale of animals of all categories.

It should be noted that milk sales, a purely commercial activity, began in the 1980s, with the opening of Tiviski, the first modern dairy in Mauritania. Farmers surveyed reported fairly high revenue of 44,829,900 MRU (≈1,134,934.17 USD)/year, with a mean value of 759,828.14 ± 531,845.21 MRU (≈19,236.15 USD)/farmer/year, ranging from 186,000 (≈4,708.86 USD) to 2,700,000 MRU (≈68,354.43 USD)/farmer/year. In addition, the sale of animals, particularly young animals, remains an important and regular source of income for all farmers, with revenue of 440,457.62 ± 466,219.88 MRU (≈11,150.82 USD)/year.

The correlation between total annual revenue and total annual expenditure of peri-urban camel herds was strong and highly significant (Pearson's r = 0.92, p < 0.01; the corresponding Spearman's rank correlation, less sensitive to the influence of the largest farms and reported alongside the other non-parametric correlations in Figure 6, was rho = 0.87). This was confirmed by the coefficient of determination (R^2) of the regression model of total annual expenditure as a function of total annual revenue, which stood at 83%. This means that farmers with higher revenue also tend to have higher expenditure (Figure 7). In addition, a few atypical farmers had revenue lower than their costs.



FIGURE 5
Distribution of revenue generated by peri-urban camel farming.

Economic situation of peri-urban camel farms

Gross margin

The margin of an activity is the difference between revenue and the total costs of that activity. A positive margin indicates that the activity is profitable, whereas a negative margin reflects a loss. Having assessed the costs relating to feed, labor, watering, animal health and other expenditure, and estimated revenue from milk and animal sales, we were able to assess the technical and economic performance of peri-urban camel farms in Nouakchott using gross margin, which takes account of both costs and revenue (Figure 8). Mean gross margin was calculated at 355,587.79 ± 459,846.78 MRU (≈9,002.22 USD)/farmer/year. However, mean annual gross margin per lactating camel is estimated at 17,583.25 ± 15,385.58 MRU (≈445.15 USD).

According to descriptive statistical analyses, 90% of farms reported a positive gross margin, ranging from 6,480 (≈164.05 USD) to 2,204,320 MRU (≈55,805.56 USD)/farmer/year. By contrast, 10% of farmers reported a negative gross margin, ranging from −331,160 (≈-8,383.79 USD) to −18,160 MRU (≈-459.74 USD)/farmer/year, indicating that they were unable to cover the full costs of camel farming. Several reasons explain the losses observed, such as high production costs or low selling prices.

Volume of animals sold

Farmers in our sample sold a total of 998 animals during the reference year, an average of 16.6 animals sold per farmer per year (mainly weaned young and dry females). The number of animals sold per farm was strongly correlated with herd size (Spearman's ρ = 0.83, p < 0.001), confirming that larger herds generate proportionally more

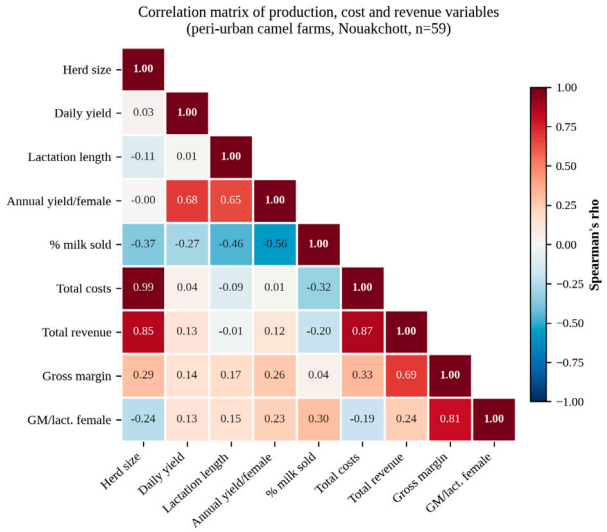


FIGURE 6
Spearman correlation matrix between the main production, cost and revenue variables of farms (n = 59). Values are Spearman's rho; darker cells indicate stronger correlations.

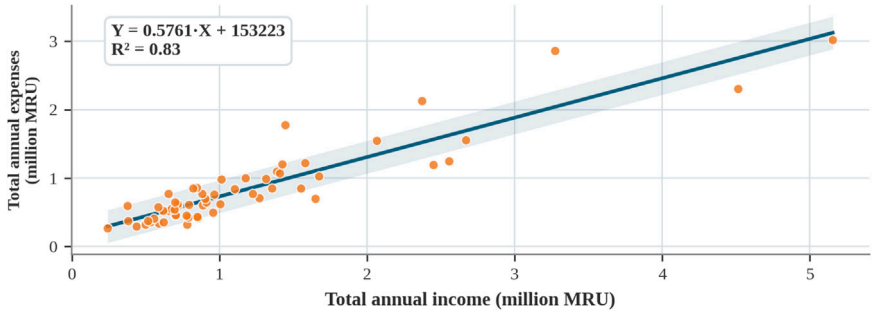


FIGURE 7
Relationship between total annual revenue and total annual costs.

animal sales rather than reflecting a distinct commercial strategy. Converting this figure into monetary value, based on the prices of the different categories of animals sold, provides an important indicator for assessing the economic contribution of peri-urban camel farming to farmers' livelihoods, as well as on the local and national economy.

Employment creation

Farmers surveyed collectively employ a total of 132 workers (125 permanent and 7 seasonal), an average of 2.23 employees per farmer, excluding family members. This employment makes a significant direct contribution to the local economy. As reported in Table 1, farms surveyed (59 farms) pay a total of 367,500 MRU per month in wages to these employees, equivalent to 12,591.8 MRU per month per farm (2.8 times the minimum wage). In addition, farmers provide benefits such as food, tea, clothing and sometimes accommodation, further contributing to these employees' economic welfare. The number of employees per farm was strongly and positively correlated with herd size (Spearman's ρ = 0.61, $p < 0.001$) and, to a lesser extent, with gross margin (ρ = 0.29, p = 0.024), confirming that employment in this system increases with farm size and, indirectly, with its overall profitability.

Characteristics associated with economic performance: correlation and multivariate analysis

Turning to RQ2, this section identifies which technical and socio-economic characteristics are most strongly associated with gross margin.

As most production, cost and revenue variables departed from a normal distribution (Shapiro-Wilk test, $p < 0.05$ for all variables except farmers' age and gross margin per lactating camel), Spearman rank correlations were calculated between the main technical and economic variables (Figure 6). Total annual revenue was strongly

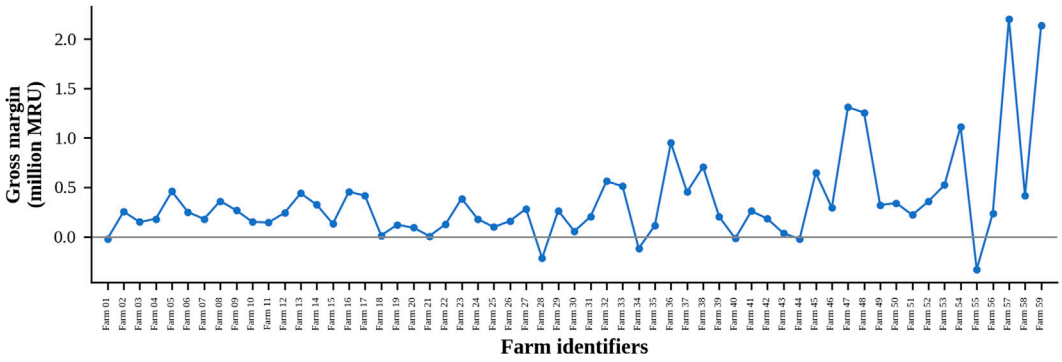


FIGURE 8
Gross margins of peri-urban camel farms.

TABLE 4 Multiple linear regression of gross margin per lactating camel (MRU/female/year) on standardized technical and socio-economic predictors (n = 59; R^2 = 0.280; adjusted R^2 = 0.197; F(6,52) = 3.38, p = 0.007), with conventional OLS standard errors and heteroscedasticity-robust HC3 standard errors shown for comparison.

Predictor	β (MRU/SD)	SE (OLS)	p (OLS)	SE (HC3)	p (HC3)	Significance (OLS)
% of milk sold	8,534.9	2,371.5	<0.001	2,100.8	<0.001	***
Lactation length	6,757.9	2,124.0	0.003	2,427.3	0.005	**
Daily milk yield	4,702.3	1,965.3	0.020	2,147.1	0.027	*
Feed cost per head	1,021.2	1,850.3	0.583	1,060.6	0.332	ns
Farmer experience	434.7	1,865.4	0.817	2,029.9	0.829	ns
Herd size	247.6	1,904.4	0.897	1,904.8	0.896	ns

*p < 0.05, **p < 0.01, ***p < 0.001 (conventional OLS p-values); ns, not significant. Coefficients are in MRU per SD of predictor; HC3 = heteroscedasticity-consistent standard errors.

and positively correlated with total annual gross margin (ρ = 0.69, p < 0.001), which was itself strongly correlated with gross margin per lactating camel (ρ = 0.81, p < 0.001), while herd size and total costs were, as expected, almost perfectly correlated (ρ = 0.99, p < 0.001), reflecting the dominant share of feed expenditure in overall costs. Daily milk yield was moderately correlated with annual milk yield per female (ρ = 0.68, p < 0.001) but not with herd size (ρ = 0.03, ns), indicating that larger herds are not necessarily more productive per animal. Gross margin was weakly but significantly related to herd size (ρ = 0.29, p = 0.025) and to annual milk yield per female (ρ = 0.26, p = 0.048), suggesting that both herd expansion and individual animal productivity contribute to farm profitability, although neither factor alone is sufficient to explain most of the observed variability.

To identify the factors most strongly associated with farm profitability once herd size is accounted for, a multiple linear regression was fitted with gross margin per lactating camel as the dependent variable, and daily milk yield, lactation length, proportion of milk marketed, farmer experience, feed cost per head and herd size as standardized predictors (variance inflation factors < 1.8 for all predictors, indicating no significant multicollinearity). The model was statistically significant (F (6,52) = 3.38, p = 0.007) and explained 28.0% of the variance in gross margin per lactating camel (adjusted R^2 = 0.20; Table 4; Figure 9). The proportion of milk sold was the strongest predictor (β = 8,535 MRU per standard deviation, p < 0.001), followed by lactation length (β = 6,758 MRU per standard deviation, p = 0.003) and daily milk yield (β = 4,702 MRU per standard deviation, p = 0.020). Herd size, feed cost per head and farmer experience were not significant predictors once these production characteristics were accounted for (p > 0.5). This result indicates that, at the level of the individual lactating camel, gross margin was associated primarily with the quantity of milk produced and marketed rather than with overall herd size or farmer experience; because gross margin is itself partly constructed from milk revenue, this association should not be read as demonstrating an independent causal effect of commercialization (see Discussion). It should also be noted that the adjusted R^2 of 0.20 indicates that around 80% of the variation in gross margin per lactating camel remains unexplained by this model, so the three significant predictors should not be read as a comprehensive account of profitability. In precise terms, the more defensible reading of this result is that, in the studied sample, herd size was not significantly associated with gross margin per lactating camel once production and marketing variables were accounted for; this should not be interpreted as evidence that herd expansion is economically unprofitable, since a true effect too small to detect at this sample size cannot be distinguished from the complete absence of an effect.

The robustness of this model was assessed through residual diagnostics and three sensitivity specifications, reported in full in

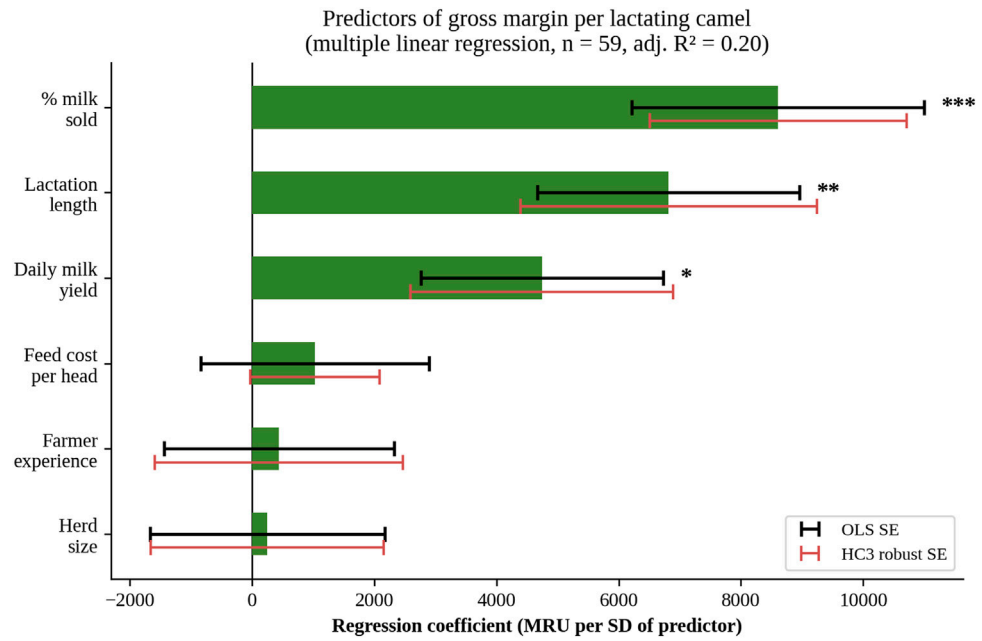


FIGURE 9
Regression coefficients (MRU per SD of predictor) for predictors of gross margin per lactating camel, with conventional OLS standard errors (black) and heteroscedasticity-robust HC3 standard errors (red) shown for comparison (Table 4). Asterisks denote significance under OLS: *p < 0.05; **p < 0.01; ***p < 0.001; ns, not significant.

Table 1. Neither the Breusch-Pagan nor the White test detected significant heteroscedasticity in the baseline model ($p = 0.998$ and $p = 0.757$, respectively), and heteroscedasticity-consistent (HC3) standard errors left every predictor's significance status unchanged; two observations exceeded the conventional Cook's distance threshold, but excluding them did not alter the pattern of results. Two further specifications tested the sensitivity of the main finding to the construction of the outcome variable: a farm-level model using total (non-ratio) gross margin as the outcome, and a milk-only margin model excluding animal-sale revenue entirely. Across both, the proportion of milk marketed, lactation length and daily milk yield remained significant positive predictors, indicating that these associations are not artefacts of the ratio construction or of including animal sales in the outcome. Herd size, by contrast, remained non-significant per lactating camel in every specification, but became a significant positive predictor once the outcome was expressed at farm level rather than per animal ($\beta = 298{,}440$ MRU, $p < 0.001$ under OLS, $p = 0.010$ under HC3 standard errors; Table 1), indicating that herd size does contribute to total farm income even though it does not explain differences in profitability per lactating camel. This distinction is developed further in the Discussion. A third sensitivity check, regressing total farm revenue, rather than gross margin, on the same six predictors, showed that herd size and the proportion of milk marketed were the strongest predictors of revenue (adjusted $R^2 = 0.82$), while daily milk yield lost significance once herd size was accounted for (Table 1); the proportion of milk marketed and lactation length nonetheless remained significant predictors of revenue as well as of gross margin, indicating that their contribution is not purely a by-product of the cost side of the gross margin identity.

As the sample was stratified across four peri-urban roadside axes around Nouakchott (Akjoujt, Rosso, Aziz and Masoud), Kruskal-Wallis tests were used to check whether economic performance differed geographically. Neither gross margin ($H = 2.25$, $p = 0.523$), nor gross margin per lactating camel ($H = 2.01$, $p = 0.570$), nor daily milk yield ($H = 6.39$, $p = 0.094$), nor herd size ($H = 6.39$, $p = 0.094$) differed significantly among the four axes, indicating that no statistically significant difference was detected among the four roadside axes; given the sample's modest and unequal size across axes (21, 17, 11 and 10 farms), this should be read as an absence of detected difference rather than as proof that the peri-urban dairy camel farming system is substantively homogeneous around the city. Likewise, a Mann-Whitney U test showed no significant difference in gross margin between illiterate farmers and those who had received formal or religious education ($U = 370$, $p = 0.993$), nor in daily milk yield ($U = 359.5$, $p = 0.877$) or herd size ($U = 335$, $p = 0.581$) between the two groups. This absence of a detected education effect is consistent with the largely informal character of the sector described above, and is compatible with the hypothesis, not directly tested here, that dairy camel profitability rests primarily on traditional know-how rather than on formal education; however, an equally plausible explanation is the limited variation in formal education within the sample (only 5.1% of respondents had formal primary education), which would limit the study's power to detect a true effect even if one existed. This conclusion should therefore be read with caution.

TABLE 5 Comparison of production and economic performance between the two main dromedary types kept by farmers surveyed (Mann-Whitney U test).

Variable	Aftout (n = 38)	Rguibi (n = 21)	U	p-value
Gross margin (MRU/year)	443,300	233,183	488.0	0.070 ns
GM/lactating camel (MRU)	19,467	15,710	436.0	0.342 ns
Daily milk yield (L/day)	5.2	5.2	349.0	0.623 ns
Lactation length (months)	12.6	11.6	436.0	0.195 ns
Annual yield/female (L)	1,926	1,843	405.5	0.648 ns
Herd size (head)	49.4	36.9	436.0	0.341 ns
Total annual costs (MRU)	934,167	717,560	430.0	0.394 ns

Effect of breed on production and economic performance

The herds surveyed comprised two locally recognized camel types, Aftout (n = 38 farms, 64.40% of the sample) and Rguibi (n = 21 farms, 35.60%). A Mann-Whitney U test was used to compare their technical and economic performance (Table 5). None of the seven variables examined differed significantly between the two types, including daily milk yield, lactation length, annual yield per female, herd size and total costs ($p > 0.19$ in all cases). Gross margin per farmer showed the largest difference, although still non-significant, with Aftout farms averaging nearly double the gross margin of Rguibi farms (443,300 versus 233,183 MRU/year, a difference of 210,117 MRU/year, or approximately 47% of the Aftout mean; $U = 488$, $p = 0.070$). Given the relatively large numerical gap combined with the modest subgroup sizes (n = 38 and n = 21), this result should not be read as demonstrating equivalent economic performance between the two types; it may equally reflect a genuine but modest breed effect that this sample lacks the statistical power to confirm. Although this trend did not reach statistical significance, it is consistent with the broader finding that farm gross margin in this system is more strongly associated with management practices, milk collection and lactation performance than with fixed animal or herd characteristics such as breed or herd size.

Taken together, these results answer the three research questions posed in the Introduction: production costs are dominated by feed (RQ1); gross margin is significantly associated with the proportion of milk marketed, lactation length and daily milk yield rather than with herd size, breed or education (RQ2); and no statistically significant differences were detected among the surveyed axes, camel types or education groups for the variables examined (RQ3), consistent with the hypothesis that milk-related production and commercial behavior, rather than herd expansion, constitute the main lever of profitability in this system.

Urban and sustainability aspects of camel farming

Beyond its direct economic benefits, peri-urban camel farming around Nouakchott is part of a longer history of adaptation to drought and urbanization. Livestock farming in the Sahel has repeatedly reorganized around cities in response to the severe droughts of the 1970s and 1980s, which decimated herds and pushed many previously nomadic households towards more sedentary, market-oriented forms of livestock farming (Blench, 2001). In this study, 54.4% of farmers reported more than 20 years of experience in peri-urban camel farming, placing the origins of this system in the decades following those droughts, while 80% of respondents confirmed the establishment of one or two new peri-urban farms nearby in just the last 3 years, evidence that the sector is still actively expanding rather than merely holding steady. Production is also reported to have declined during the first 2 years of the COVID-19 pandemic (2020-2021) before recovering from 2022 onward, and a similar growth trend in peri-urban camel herds has been documented elsewhere in Mauritania (Ould Ahmed et al., 2024).

Policy environment and market development

The Mauritanian government has begun to formalize institutional support for the sector through the establishment of the Mauritanian Centre for Camel Farming Development (CMDEC), created in 2017 as a supervisory and extension body aimed at integrating camel farming into economically viable production systems. At the same time, private operators have begun to diversify the product range beyond raw milk - pasteurized milk, yoghurts and cheeses - to serve urban consumers, while producers increasingly combine farm-gate sales with informal online and direct-sale channels. This evolution reflects the broader repositioning of camels, once regarded mainly as desert transport and subsistence animals, into recognized economic assets for peri-urban households (Faye et al., 2011; Ait El Alia et al., 2025). Sustaining this momentum will, however, require structuring the value chain from production and cold storage through to processing and distribution, well beyond its still largely informal, short-circuit character.

Environmental sustainability and the value of halophytic plants

When well-managed, camel farming can be more sustainable than other forms of livestock farming. Camels are adapted to harsh

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FIGURE 10
Camels on peri-urban pastures dominated by salt-tolerant plants.

climatic conditions and have a lower environmental impact. The integration of camel farming into urban and peri-urban systems on the outskirts of Nouakchott rests on a combination of factors related to the animal's adaptability to its environment, as well as to the socio-economic and cultural dynamics at play. The surrounding grazing areas are dominated by halophytic plants such as *Zygophyllum gaetulum* and *Zygophyllum simplex*, which were identified in the field by the study team rather than through a formal botanical survey, and which appeared, from field observation, to be favored by dairy camels (Figure 10). Environmentally and nutritionally, the dromedary makes good use of these marginal, salt-tolerant-plant-dominated areas. It should be noted that all farmers graze their animals on this land.

The transition from traditional nomadic camel farming to a peri-urban model involves reconciling traditional methods with modern innovations for long-term sustainability. This shift aims to strengthen resilience to climate change by adopting climate-smart practices such as farm-gate and online camel milk sales, the use of halophytic plants, and the implementation of water management techniques. Integration into the peri-urban system aims to improve food security, strengthen resilience and ensure the viability of camel-farming activities. This may involve value-chain integration, direct sales, or the creation of agri-food enterprises in Mauritania.

Discussion

The profitability analysis of peri-urban camel farming in Nouakchott confirmed the economic feasibility of this activity, generated mainly by milk sales (65.4% of revenue) and constrained mainly by feed costs (73% of expenditure), a cost structure consistent with that reported for dairy cattle farming elsewhere in Mauritania (El Hadj et al., 2024). Milk and meat are the main sources of monetary income for farmers, with milk sales playing a central role given strong demand in the Nouakchott urban market and the broader global expansion of camel milk markets (Faye et al., 2011; Ait El Alia et al., 2025). This finding of economic feasibility rests here on a multi-level statistical approach descriptive statistics, rank correlations, non-parametric tests and standardized multiple regression whose convergence, rather than any single result, constitutes the foundation of robustness for the analysis developed in the following sections.

Socio-demographic profile and experience of farmers

The demographic characteristics of farmers surveyed in Nouakchott, mean age of 47.95 ± 16.55 years, mean experience of approximately 19.5 years (54.4% of farms in existence for more

than 20 years) and households of 5.36 ± 1.32 people, differ markedly from those reported in other peri-urban camel systems in the sub-region. In Khalil et al. (2021) report camel-farming household heads who are considerably younger (31.52 ± 9.3 years) and have been settled on the urban periphery for 13.26 ± 9.2 years on average, but who head substantially larger households (8.3 ± 3.2 people). This substantial age gap may reflect different settlement trajectories: whereas the Chadian system described by these authors is based on young household heads sent to the urban periphery while the bulk of the herd and family remain in the area of origin, the older profile observed in Nouakchott suggests more established peri-urban settlement, consistent with farmers who have completed their transition to decentralization rather than by young pioneers in the process of settling. In Biya et al. (2021), in a typology covering 187 camel farms across the country's four regions, report a farmer illiteracy rate of 20.9%, lower than the 30.5% observed in our peri-urban Nouakchott sample a gap that might seem counter-intuitive given urban proximity, but which remains consistent with our own findings showing that education level does not explain economic performance in this system, and which cautions against equating urban proximity with better access to formal education for this population of farmers. These comparisons, although limited by the heterogeneity of survey protocols and definitions used across countries, suggest that the socio-demographic profiles of peri-urban camel farmers in the Sahel are far from homogeneous and deserve to be documented specifically for each production basin rather than extrapolated from one national context to another.

Characteristics associated with profitability

Dairy farms generated an average annual gross margin of 355,588 MRU (9,002 USD) per farmer, with 90% of farmers profitable and 10% operating at a loss. Multiple regression analysis (Table 4) showed that gross margin per lactating camel increased significantly with the proportion of milk marketed, lactation length and daily milk yield, whereas herd size, feed cost per head and farmer experience were not significant once these production characteristics were accounted for. This pattern echoes findings on the economic values of production and functional traits in other dairy farming systems, where milk collection and lactation performance consistently emerge as the variables most strongly associated with farm profitability, ahead of herd size or input costs (Kahi and Nitter, 2004; Wahinya et al., 2015; Hietala et al., 2014; Ghiasi et al., 2016; Cervo et al., 2017; Malenje et al., 2022). A similar dependence on milk collection as the main guarantee of household income has been reported among peri-urban camel-farming households in Chad (Mahamat Ahmat et al., 2023). Interestingly, this contrasts with evidence from smallholder dairy systems outside the camel sector: in Kenya, herd size and education significantly reduced profit inefficiency among smallholder dairy producers (Nganga et al., 2010), and herd size remained significantly and positively associated with normalized profit among dairy farmers in southern India (Lakshmipriya et al., 2023). The absence of a herd-size effect in the present study suggests that, in this Sahelian peri-urban system, milk collection and commercial behavior, rather than scale, constitute the binding constraint on profitability, probably because feed costs increase almost linearly with herd size ($\rho = 0.99$ between herd size and total costs; Figure 6), leaving little marginal benefit from herd expansion alone. The consistency of this finding across three distinct lines of evidence, the non-significance of herd size in the multivariate regression, the absence of correlation between herd size and daily milk yield ($\rho = 0.03$, ns), and the near-absence of a gross-margin gap between farms of different sizes once collection practices are accounted for strengthens the credibility of this conclusion, which therefore does not rest on a single isolated statistical test but on a body of converging evidence.

This finding nonetheless requires an important qualification, revealed by the sensitivity analyses reported in Table 1. When gross margin is expressed at the level of the whole farm rather than per lactating camel, herd size re-emerges as a significant positive predictor (β = 298,440 MRU, $p < 0.001$ under OLS, $p = 0.010$ under heteroscedasticity-robust standard errors), while the milk-marketing and lactation variables remain significant in both specifications. Herd size therefore does contribute to total farm income, larger herds mechanically generate more total revenue and more total margin, but it does not explain why some farms are more profitable than others per animal kept, which is the question this study set out to answer. The recommendation to prioritize milk collection and lactation management over herd expansion (Conclusion) should accordingly be read as applying to profitability per animal rather than to total farm income, for which scale remains relevant; farmers or programs seeking to raise total household income through herd growth are not contradicted by this study, but should not expect herd growth alone to improve the profitability of each animal kept.

This pattern also helps reconcile an apparent discrepancy between the bivariate and multivariate results: gross margin was weakly but significantly correlated with herd size at the bivariate level ($\rho = 0.29$, $p = 0.025$; Section 3.7), yet herd size was not a significant predictor once other variables were controlled for in the multiple regression. Rather than being contradictory, this pattern is consistent with the near-perfect collinearity between herd size and total costs ($\rho = 0.99$) described above: because feed expenditure scales almost proportionally with herd size in this sample, the herd-size and feed-cost variables capture largely overlapping information, so that once feed cost per head and the other production variables are held constant in the multivariate model, little independent variation in herd size remains to explain gross margin. The bivariate correlation therefore likely reflects this same underlying scale effect rather than a distinct herd-size effect that disappears once other variables are added.

Homogeneity across axes, breeds and education levels

Turning finally to RQ3, this section tests whether gross margin differs significantly according to geographic axis, camel breed or farmer education level.

The results also confirm a near-absence of geographic effect within the peri-urban system: gross margin, milk production and herd size did not differ significantly among the four roadside axes surveyed around Nouakchott. Likewise, farmers' formal education level showed no measurable association with economic performance, consistent with observations from other peri-urban

farming systems in West Africa, where high rates of illiteracy among farmers did not constitute a barrier to the adoption of improved management practices (Amadou et al., 2012). A comparable pattern was observed between camel types: neither the Aftout nor the Rguibi type showed significantly different production or economic performance, although Aftout farms tended to report higher gross margins. Together, these results indicate that, within the range of animals and zones covered by this survey, farming practices and milk-collection decisions outweigh fixed animal or geographic characteristics as correlates of profitability. This triple test of homogeneity - geographic, breed-related and educational - is rarely conducted so systematically in the literature on peri-urban camel farming, where comparisons between sub-groups are most often limited to a single dimension; by successively ruling out three plausible alternative explanations for the observed variability in profitability, this analysis strengthens the robustness of attributing that variability to management practices rather than to structural factors that public policy cannot readily change.

Farmers' decisions regarding the fate of camels after lactation likewise reflect this management-oriented logic. As noted above, the comparison between farms reporting a single post-lactation practice and those combining several showed no significant difference in gross margin, nor in gross margin per lactating camel. This suggests that, unlike milk collection, the specific post-lactation destination of animals does not in itself constitute a strong correlate of profitability in this sample, although the practice, noted by some farmers, of selling high-quality breeding females is flagged here as a potential long-term concern for herd genetic quality rather than as a conclusion established by this study, since genetic quality, breeding value, replacement rates and long-term herd productivity were not directly measured and cannot be captured by an economic indicator covering a single season.

Dynamics and peri-urban expansion of camel farming

Beyond the case of Nouakchott, recent literature confirms that the growth of peri-urban camel farming constitutes a structural trend across the Sahel and North Africa, rather than a localized phenomenon. Faye et al. (2026) show that the Sahelian camel herd now accounts for more than a third of the world's camel population, with milk and meat production estimated at approximately 463,000 and 50,000 tons respectively in 2023, volumes that the authors consider still substantially underestimated owing to a lack of systematic field data, which underscores the value of localized surveys such as the present study. This demographic growth is accompanied by a profound reorganization of production systems: Faye and Corniaux (2024) describe a transition of camel milk from a gift economy, rooted in pastoral social networks, to a market economy structured around urban and peri-urban collection basins, a transition confirmed by our own findings regarding the central role of milk sales in surveyed farmers' income. Comparable dynamics are documented elsewhere in the region: in Morocco, Amsidder et al. (2024) show that camel systems in the southern and eastern provinces contribute increasingly to the local economy as they become integrated into urban markets; in Senoussi et al. (2024) describe the emergence of peri-urban farms on the outskirts of Saharan cities, linked to a diversification of the dromedary's functions (production, tourism, security) that now extends beyond its traditional pastoral role. This regional dynamic was, moreover, given institutional recognition through the United Nations' decision to designate 2024 the International Year of Camelids, in recognition of this species' growing role in food security and economic resilience in arid areas (FAO, 2024). The case of Nouakchott, where 80% of farmers surveyed report the establishment of new peri-urban farms within just the last 3 years, illustrates this regional expansion at the local scale, while also revealing, through the econometric analysis conducted here, the specific levers - labor and milk collection - associated with its economic success.

Policy implications and value-chain development

These findings have direct implications for public policy and value-chain development. As camel farming continues to shift from a subsistence activity to a market-oriented one across the Sahel and North Africa (Farah et al., 2004), with the emergence of peri-urban mini-dairies around cities in Mauritania, Niger, Djibouti, Kenya, Morocco and Algeria (Noor et al., 2012; Mammeri et al., 2014) and the development of more industrialized dairies in Gulf countries (Babiker, 2014), the case of Nouakchott illustrates both the opportunities and the fragility of this transition. Because profitability here depends mainly on milk collection and lactation management rather than on herd size, extension and investment programs are likely to have greater impact if they prioritize improving milk collection, access to the cold chain, and lactation management (for example, increased milking frequency, weaning practices) rather than incentives for herd expansion. Strengthening farmer organization and market linkages would further help ensure that the observed profitability translates into lasting resilience for peri-urban camel farmers. This orientation echoes lessons drawn from dairy cattle value chains in East Africa, where the persistence of informal channels dominated by rapidly perishable raw milk structurally limits smallholders' access to quality standards and remunerative markets, and where the cooperative model has proven an effective lever for pooling collection, reducing transaction costs and progressively improving compliance with standards without excluding informal producers (Kilima et al., 2024). Applied to the camel context of Nouakchott, this finding suggests that support for pooled collection arrangements, rather than interventions targeting each farm in isolation, could substantially amplify the effect of the cold-chain investments recommended above.

Practical implications and research perspectives

Beyond these policy-level recommendations, the findings also carry practical implications for farmers and extension workers, and point to concrete directions for future research. At farm level, the results support prioritizing achievable, low-cost changes in daily practice such as considering a shift from twice-to thrice-daily milking as a potential management option for further evaluation shown elsewhere to raise output by up to 28.5% (Kamoun, 1995), but requiring local assessment of the additional labor, costs, animal-

management implications and actual net economic benefit under Nouakchott production conditions before it can be recommended—and reconsidering the routine sale of high-yielding females after lactation, given its potential long-term effect on herd genetic quality over costly herd-expansion strategies whose profitability this study did not confirm. For cooperatives and collection initiatives already forming around Nouakchott, the results suggest that pooling milking and collection labor across neighboring farms could extend the benefits identified here (see "Employment creation on peri-urban dairy camel farms" section) to smaller households currently unable to hire permanent staff. Looking ahead, priority research directions include longitudinal, multi-season monitoring to capture the seasonal and inter-annual variability that a single cross-sectional survey cannot address; a comparative genetic and reproductive evaluation of the Aftout and Rguibi types, motivated by the marginally non-significant gross-margin gap observed between them (see "Effect of breed on production and economic performance" section) demand-side research on urban consumers' willingness to pay for quality-assured or processed camel milk, to inform the value-chain investments recommended above; and ex-ante cost-benefit analysis of cold-chain and pooled-collection interventions before they are scaled up, to ensure that the labor-focused levers identified in this study translate into affordable, sustainable investments for peri-urban camel-farming households.

Originality and credibility of the study

Several features distinguish this study from earlier work on peri-urban camel farming in the Sahel, which has been mostly descriptive (Noor et al., 2012; Mammeri et al., 2014; Gebremichael et al., 2019; Mahamat Ahmat et al., 2023), and underpin its credibility. To our knowledge, it is the first study in this context to combine descriptive statistics, rank correlations, non-parametric tests and standardized multiple regression within a single multi-method framework, with the significance and direction of each main finding corroborated by at least two complementary analytical approaches applied to the same sample, limiting the risk that an isolated result reflects a statistical artefact rather than a genuine phenomenon. Its central finding, the primacy of milk collection and lactation management over herd size, contrasts with comparable non-camel smallholder dairy systems (Nganga et al., 2010; Lakshmipriya et al., 2023), suggesting that profitability in peri-urban camel farming cannot simply be extrapolated from the dairy-cattle literature and calls for extension policies tailored to this species. Finally, the recommendations set out in the Conclusion are grounded directly in quantified effect sizes and their statistical significance, rather than in unverifiable generalizations, a feature that responds directly to this journal's 'Policy and Practice' remit.

Limitations of the study

This study has several limitations that should be taken into account when interpreting its results. First, the sample of 60 farms, although consistent with similar surveys on peri-urban farming in the sub-region, limits the statistical power of the multivariate analyses and the generalizability of the results beyond the Nouakchott area. Second, cost and revenue data were drawn from farmers' verbal declarations rather than from farm accounting records, as camel farming in Mauritania is largely part of the informal sector; this may introduce recall or reporting bias, particularly for infrequent expenditure. Third, the single-visit cross-sectional design captures a snapshot of the 2023-2024 production season and does not account for seasonal or inter-annual variability in milk production, prices and costs, which is known to be substantial in Sahelian pastoral systems.

On the analytical side, the multiple regression model explained only a moderate share of the variance in gross margin per lactating camel (adjusted $R^2 = 0.20$), implying that other unmeasured factors, such as pasture quality or animal genetics, likely contribute to the remaining variability and would merit further investigation, ideally through longitudinal monitoring of a larger panel of farms. In addition, as farms were sampled along the main paved roadside axes leading out of Nouakchott, the sample may under-represent camel farms located further from these axes and less accessible to enumerators and, potentially, to milk buyers; such farms could differ systematically in their commercial behavior and profitability. Geospatial sampling methods combining satellite imagery and analysis of camp distribution, increasingly used in pastoral research to reach mobile populations otherwise invisible in conventional surveys, offer a concrete methodological avenue for future studies seeking to also represent the least accessible peri-urban camel farms away from roadside axes.

Lastly, the gross margin reported throughout this study is a cash gross margin: it is calculated from monetary costs and revenue only, and does not include depreciation of productive assets, the opportunity cost of unpaid family labor, the opportunity cost of grazing land, or changes in herd inventory value. This is consistent with the informal, cash-based nature of record-keeping in this system, and with common practice in comparable farm-level studies (Nkadimeng et al., 2021; Cervo et al., 2017), but it means that the indicator should not be read as a complete measure of economic profit or of the long-term viability of these farms; a fuller accounting would likely narrow the margins reported here, particularly for farms relying heavily on unpaid family labor.

Conclusion and recommendations

Mauritania's peri-urban camel production system is expanding in response to growing demand for camel milk, both as a food and as a medicinal product. This market-oriented pattern reflects the evolving role of camels in meeting market needs, providing nutrients, income and social ties to farmers.

A study conducted in Nouakchott highlights the role of camel farming as a sustainable source of income, with the sale of raw camel milk constituting farmers' main monetary revenue, exceeding the minimum wage threshold.

Peri-urban camel farming has the potential to improve economic welfare and support livelihoods, underscoring the importance of future research. This highlights the need for further research on value-chain dynamics, including detailed analyses of production flows, distribution mechanisms and the roles of the various actors involved, such as farmers, collectors, transporters and traders. Although often overlooked in Sahelian countries, camels' adaptability and their integration into urban settings can strengthen food security in the region.

Challenges facing the camel milk value chain include inadequate selection practices, limited marketing services, traditional taboos and a lack of institutional and technical support. Beyond these general challenges, the statistical associations identified in this study give rise to four specific, evidence-based recommendations:

- For milk collectors, cooperatives and value-chain investors, given that the proportion of milk marketed is the factor most strongly associated with profitability per animal (β = 8,535 MRU/standard deviation, $p < 0.001$), programs should prioritize reducing post-harvest losses and strengthening the cold chain and collection infrastructure over incentives for herd-size expansion as a means of raising profitability per animal; herd growth remains a legitimate lever for raising total farm income as such (Discussion), but sensitivity analyses indicate that it should not be relied upon to improve the profitability of each animal kept.
- For livestock extension services, because lactation length and daily milk yield were also significant predictors of gross margin ($p = 0.003$ and $p = 0.020$, respectively), they should focus on improving milking practices and feed management during lactation rather than on herd growth alone; specifically, increasing milking frequency (for example, moving from twice-to thrice-daily milking) is a plausible hypothesis worth testing through extension trials or a formal cost-benefit analysis, including its effects on calf nutrition and welfare and on labor costs, rather than an intervention whose net economic benefit this study has directly demonstrated.
- For community-engagement programs, since the absence of a detected association with herd size or education is compatible with the hypothesis that traditional farming know-how may play an important role in technical performance, awareness-raising initiatives should build on farmers' existing knowledge rather than assuming a knowledge deficit, while continuing to address the traditional taboos that limit market participation.
- For public policymakers, because no statistically significant difference in economic performance was detected across the four peri-urban roadside axes surveyed, institutional and technical support programs could initially be designed for the peri-urban system as a whole rather than targeted at specific zones, which would simplify implementation and reduce deployment costs; this should, however, be treated as a provisional starting point rather than a settled finding, since factors not measured in this study, such as market access, infrastructure, distance to consumers, milk-collection arrangements and feed availability, could still differ meaningfully across axes even where the variables assessed here do not.

Implementing these recommendations can strengthen the camel milk value chain and contribute to the economic welfare of peri-urban farmers in Mauritania.

Data availability statement

The raw data will be made available on reasonable request to the corresponding author.

Ethics statement

The animal study was approved by Research Ethics Committee of the Ecole Supérieure Agronomique et Vétérinaire de Rosso 2023/2024. The study was conducted in accordance with the local legislation and institutional requirements.

Author contributions

MOA: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Supervision, Validation, Writing original draft, Writing-review and editing. YEH: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Writing-review and editing. MME: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Writing review and editing. EHEM: Methodology, Writing-review and editing. SH: Data curation, Writing-review and editing. AH: Formal analysis, Writing-review and editing. SBSR: Formal analysis, Writing - review and editing. AOMSB: Supervision, Validation, Writing-review and editing. M'ND: Supervision, Validation, Writing-review and editing.

Funding

The author(s) declared that financial support was not received for this work and/or its publication.

Acknowledgments

We are extremely grateful to the breeders for their active participation in this study. We would also like to thank the technicians and professionals for their invaluable support in data collection. Additionally, we extend our thanks to our colleague Jeyid Yacoub Daye for its support and preparing the study-area map. The authors are thankful to the anonymous reviewers for improving the quality of the manuscript. We would like to extend our sincere thanks to the Editor in-Chief of the Pastoralism: Research, Policy and Practice and his staff for their valuable efforts in the service of science.

Conflict of interest

The authors(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

The author(s) declared that generative AI was used in the creation of this manuscript. During the preparation of this work, the authors used Claude (Anthropic) and ChatGPT (OpenAI) to assist with translation, language editing, organization, and formatting. After using these tools and

services, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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