Retail practices and preservation methods for camel milk in Laâyoune-Sakia El Hamra, Morocco

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Submitted: February 4, 2026, **Accepted:** June 10, 2026, **Published:** June 15, 2026.

Abstract

Camel milk represents an essential food in Southern Morocco, both culturally and nutritionally. The way it is handled and preserved during the retail process has a great impact on its safety, shelf life and marketing. We aimed to characterise the practices involved in the retailing of camel milk in the Laâyoune-Sakia El Hamra region. We carried out a cross-sectional survey of all the retailers in four provinces between November 2024 and February 2025. We collected data through a structured questionnaire focusing on milk sourcing, supply organisation, transport, storage, preservation, packaging, prices and consumer preferences. A total of 61 retailers were interviewed in this study. The milk was supplied by 21 different communes, mainly from Oued Saguia and Hagounia in Laâyoune. Retailers bought their milk from up to four breeders. The milk was usually supplied in the early morning and quickly stored in the refrigerator (around 4°C) for short periods (about 24 h). When milk could not be sold, it was generally turned into the traditional fermented product "Frick", which seems to imply a low-waste preservation strategy. Consumer preference was mainly for fresh milk and, secondly, for fermented milk or a mix of both. According to multivariate and classification analyses, the practices adopted in the different provinces seemed to vary based on the origin and prices of the milk. These findings suggest that improvement efforts should focus on cold-chain management, hygiene as well as packaging practices, sourcing traceability, and safer handling of the fermented camel milk.

Key words: camel milk retail, cold chain, frick, laâyoune-sakia el hamra, preservation techniques

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1. Introduction

Camels belong to the family Camelidae, the sub-order Tylopoda within the order Artiodactyla and comprise two domesticated and one wild species: the Bactrian camel (Camelus bactrianus), characterised by two humps, the Arabian or dromedary camel (Camelus dromedarius), characterised by one hump, and the wild Bactrian camel (Camelus ferus). The dromedary camel occupies desert and dryland regions of the Old-World camelids and is notably adapted to hot, arid, and semi-arid regions. For centuries, the dromedary has been a cornerstone of pastoral systems in North Africa and the Middle East. In Southern Morocco in particular, it plays a major economic and socio-cultural role for nomadic and semi-nomadic populations. Beyond its symbolic value as a marker of desert heritage, it contributes to transport and sport, while also providing meat and milk. Additionally, camel hair is traditionally utilised for clothing and tents, while camel skin is

used to create handcrafted items like belts and shoes (Niasari-Naslaji, 2009). Camel production systems enhance lives and promote food security in arid regions through their numerous applications and products (Suliman et al., 2019).

In 2024, there were an estimated 44 million camels worldwide, according to the most recent FAOSTAT data. In 2025, there were 106,044 camels in Morocco (Ministère de l'Agriculture et de la Pêche Maritime, 2025). The southern parts of Morocco are home to the majority of camels. Because of its nutritious significance, camel milk is one of the camel products that is getting more attention (Konuspayeva et al., 2022). Because of this, camel milk is becoming more and more popular in local and regional markets. Camel milk is frequently consumed by the local populace due to its high content of vital nutrients, vitamins, and minerals. Since camel milk is primarily drunk raw, its commercial development is still small despite tremendous demand.

Camels typically take 8 to 18 months to lactate, and each she-camel produces between 1,000 and 4,000 kg of milk annually (Boujenane, 2020). Camel milk yields are usually high, with peak yields of 4–10 kg, commonly attained within 2–7 months post-calving and persistency >85% (Boujenane, 2020). Formal infrastructure for milk collection and processing remains limited in Southern Morocco, and retail is the main channel through which consumers purchase camel milk. As a result, retail operations are essential for ensuring product availability, preserving quality and shaping consumer perceptions of that quality.

Thus, by surveying retailers and recording (i) milk sourcing locations, (ii) transport and reception conditions, (iii) post-reception handling and storage practices, (iv) preservation pathways including refrigeration and traditional fermentation, and (v) pricing patterns and consumer preferences, this study offers an organised characterisation of the camel milk retail chain in the Laâyoune–Sakia El Hamra region. In addition to providing descriptive reporting, the study synthesises these variables to determine the primary profiles and factors that shape retail practices. This provides a foundation of evidence to direct realistic improvements in cold-chain management, hygiene, and viable options for adding value that are tailored to regional limitations and consumer expectations.

2. Materials and Methods

2.1. Study area

The Laâyoune–Sakia El Hamra region (southern Morocco), which spans an area of around 140,018 km², is the main camel-breeding area in Morocco, with over 90% of the national camel herd located there (Amsidder et al., 2024). Although there is a noticeable temperature difference between summer and winter and relatively little yearly rainfall in the area, temperatures remain moderate along the Atlantic coastal belt. Livestock production is the primary agricultural activity and a significant source of income for pastoral households. Camel breeding is the most common activity in regional livestock systems and makes up a sizable portion of all herds. A map of the study area is provided in Figure 1.

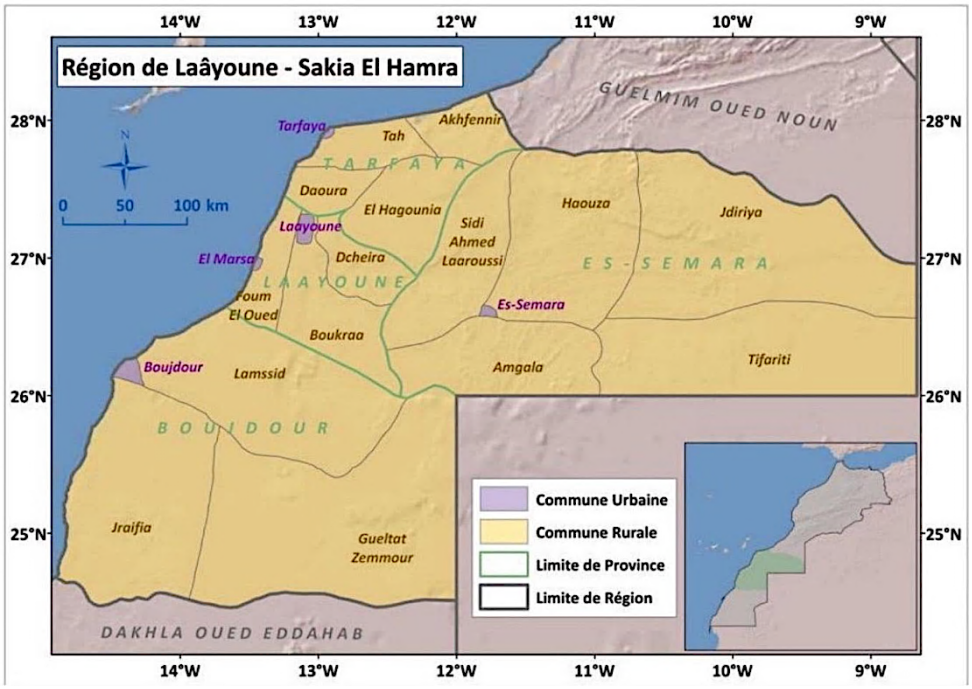

Figure 1. Map of the Laâyoune-Sakia El Hamra study area showing the four survey provinces (Laâyoune, Es-Semara, Boujdour, and Tarfaya), Morocco.

2.2. Survey design, target population, and data collection

To describe camel milk handling and commercialisation procedures along the retail channel, a cross-sectional field survey was conducted. All identified sellers were requested to participate in a comprehensive census of camel milk vendors in the area (n = 61). There were retailers in four provinces: Tarfaya (n = 2), Boujdour (n = 9), Es-Semara (n = 10), and Laâyoune (n = 40).

We used a standardised questionnaire for in-person interviews to gather data, which we reinforced where necessary by conversations with suppliers, retailers, or herders to clarify operational specifics and regional jargon. The interviews were performed by members of the research team who were knowledgeable about the camel production systems and local retail practices in the study area. Prior to data collection, we examined the questionnaire to make sure the questions were relevant for the local context, clear, and consistent. Interviewers used the same structured questionnaire in order to reduce interviewer-related variability. We used Microsoft Excel to enter the replies prior to statistical analysis. Data accuracy was confirmed using field notes, consistency checks during data input, and post-entry screening in Excel. We compared uncertain or inconsistent responses to the original questionnaire data and clarified them when necessary.

2.3. Questionnaire content and study variables

The questionnaire was designed to capture the key axes of camel milk retail operations (Table 1). It covered: (i) retailer profile and activity context, including identification and location, and experience in milk retailing and organisation of the activity; (ii) milk sourcing, handling, and preservation practices, including milk origin and procurement structure, logistics, volumes and

cold-chain practices; and (iii) commercialisation and development, including packaging and sale modalities, pricing and turnover indicators, traditional processing or product development, and consumer preference indicators.

2.4. Data management and preprocessing

The cleaned dataset was loaded into R after being exported from Excel to a CSV file. To ensure comparability between multivariate processes, incomplete records were eliminated using listwise deletion (i.e., na.omit), and variables were typed according to their measurement scale (continuous variables encoded as numbers, categorical variables encoded as factors).

Table 1. Collected data of retailers: axes, variables, and indicators captured in the questionnaire.

Axis	**Data**
Retailer profile and activity context	Identification and location (name, address, contact) Experience in milk retailing and organisation of the activity
Milk sourcing, handling, and preservation practices	Milk origin and procurement structure (origin area, number of suppliers) Logistics (time of milking, time of reception, transport containers/conditions) Volumes and cold-chain practices (quantity received, storage equipment, storage temperature and duration)
Commercialisation and development	Packaging and sale modalities Pricing and turnover indicators (quantities purchased and sold) Traditional processing/product development (e.g., fermented product preparation, equipment used, fermentation duration) Consumer preference indicators

2.5. Statistical analyses

All analyses were performed in R. The workflow combined (i) descriptive statistics and visualisation, (ii) multivariate exploration for mixed-type survey data, and (iii) supervised classification to identify practice patterns most predictive of geographic provenance.

2.5.1. Descriptive statistics and visualisation

The most pertinent results are shown in the Results section. Retailer practices and commercialisation indicators were characterised across provinces using descriptive statistics and graphical summaries. To account for small sample strata and non-normal distributions common to field survey variables, group comparisons were carried out using a non-parametric framework. Statistical visualisations were generated using R packages designed to provide effect sizes and inferential details with plots.

2.5.2. Multivariate structure of retailer practices (Factor Analysis of Mixed Data; FAMD)

Factor Analysis of Mixed Data (FAMD), which combines the logic of Principal Component Analysis (PCA) for continuous variables and Multiple Correspondence Analysis (MCA) for categorical variables, was used to reduce

dimensionality because the survey combined categorical variables (such as province, packaging type, storage equipment) and continuous variables (such as quantities, price, fermentation duration). Numeric variables were standardised internally by the FAMD implementation, ensuring balanced contributions of continuous variables without manual preprocessing. Principal dimensions were interpreted based on eigenvalues and explained variance, using the common eigenvalue > 1 heuristic to retain dimensions carrying more information than a single standardised variable.

To summarise heterogeneous retailer profiles into practice "types," hierarchical clustering was then performed on the retained low-dimensional coordinates using Ward's criterion (i.e., clustering in the FAMD feature space).

2.5.3. Province-level classification and variable importance (Random Forest)

Using random forests, a supervised classification model was created to measure the degree to which retailer practices distinguish provinces and to determine the most significant predictors. Numerical variables were scaled in a single step before training. Out-of-bag (OOB) error calculated from forests of 500 trees was used to guide selection, and model tuning investigated various values of mtry (number of candidate predictors at each split). OOB error and a confusion matrix were used to describe the model performance after the final random-forest classifier was trained to predict province from the complete set of retailer-practice variables. The Mean Decrease in Gini index was used to rank the variables that were most responsible for province discrimination.

3. Results

3.1. Retail structure, sourcing geography, and daily milk-flow logistics

An extensive survey among 61 camel-milk retailers was conducted across the four provinces of Laâyoune-Sakia El Hamra (November–December 2024; January–February 2025). The survey showed that 66% of retailing activity occurred in Laâyoune, with a smaller share in Boujdour (16%), Es-Semara (14%) and Tarfaya (4%) (Figure 2A). Regarding milk origin, 21 communes from which milk is collected were identified. A limited number of supply origins dominated the market (Oued Saguia, ~50%; Hagounia, ~30%, etc.), while the remaining supply origins accounted for a minor fraction of the total supply (Figure 2A).

Most retailers received their milk supply from a single breeder, although some used up to four suppliers. Some retailers were also breeders (Figure 2B). Most retailers had a daily milk collection schedule. Depending on the season, breeders typically reported two milking sessions per day, at approximately 22:00 and 05:00. Milk was typically collected by retailers in the morning, at around 07:00 (Figure 2C). After receipt, milk was typically kept refrigerated at around 4°C. Storage duration varied among retailers. Most retailers stored milk for only 24 hours, while about 20% stored it for 12 to 18 hours, and a small percentage stored it for 48 to 72 hours (Figure 2D).

3.2. Preservation pathways, fermentation variability, and commercialisation patterns

Retailers reported a strong "no-waste" preservation logic that extends beyond refrigeration: if fresh milk is not sold within a day, it is typically fermented traditionally into "Frick", an acidic fermented product that can be stored for a few days to weeks is produced by fermentation in a "Tasoufra" container made of sheep's skin. The large range of fermentation times, from about 5 to 12 hours and infrequently up to 24 hours, indicates that season and consumer desire may have an impact on acidity. According to retailer data, 60% of consumers preferred fresh camel milk, 20% preferred Frick,

and 20% consumed both, demonstrating fresh milk's dominant market position. Retailers' commercial throughput differed greatly. The average daily purchase was about 30 L, with a range of 15 to 160 L. Retailers said that a substantial proportion of milk was sold on the same day and that the remaining volumes were transformed into Frick before being sold, despite the absence of industrial processing. This is in line with high demand and limited spoilage. Fresh and fermented milk were often offered at the same retail price (14 MAD/L), while the purchase price from breeders was often 10–11 MAD/L. This suggests a small per-litre margin that was countered by rapid turnover and low losses.

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3.3. Multivariate and machine-learning synthesis: what truly differentiates provinces

The multivariate analysis of the mixed survey dataset (FAMD) showed that retailer practices were structured by several weak gradients rather than by a single dominant axis. The first three dimensions explained approximately 25.06% of the total variance (Dim1: 11.65%, Dim2: 6.79%, Dim3: 5.73%) (Figure 3A). The projection of retailer observations on the first three dimensions showed visible province-level structuring, with separation mainly associated with milk origin and price-related variables (Figure 3B)

Random-forest classification confirmed this pattern: province was predicted from retailer-practice variables with a low out-of-bag (OOB) error of 3.28%, with near-perfect classification for Laâyoune and Tarfaya, and limited confusion mainly between Boujdour and Es-Semara (Figure 4A). Variable-importance results identified a small set of highly discriminant predictors: Frick price (MeanDecreaseGini ≈16.63) and milk origin (≈9.12) dominated, followed by milk price (≈3.25), milking time (≈0.84) and consumer preference (≈0.81), while several variables contributed little to discrimination (e.g., availability and transport equipment showed near-zero importance in the fitted model) (Figure 4B). Taken together, the machine-learning results indicate that provincial micro-markets are primarily differentiated by price formation and sourcing geography, more than by the basic preservation logic (refrigeration + fermentation), which appears broadly shared across the region.

In contrast, predicting fermentation duration as a categorical outcome from the recorded variables performed poorly (OOB error: 44.26%). This suggests that fermentation time is influenced by important unmeasured drivers (e.g., ambient temperature/season, container microbiota and "back-slopping," hygiene practices, batch history), and therefore cannot be reliably inferred from the current questionnaire variables alone.

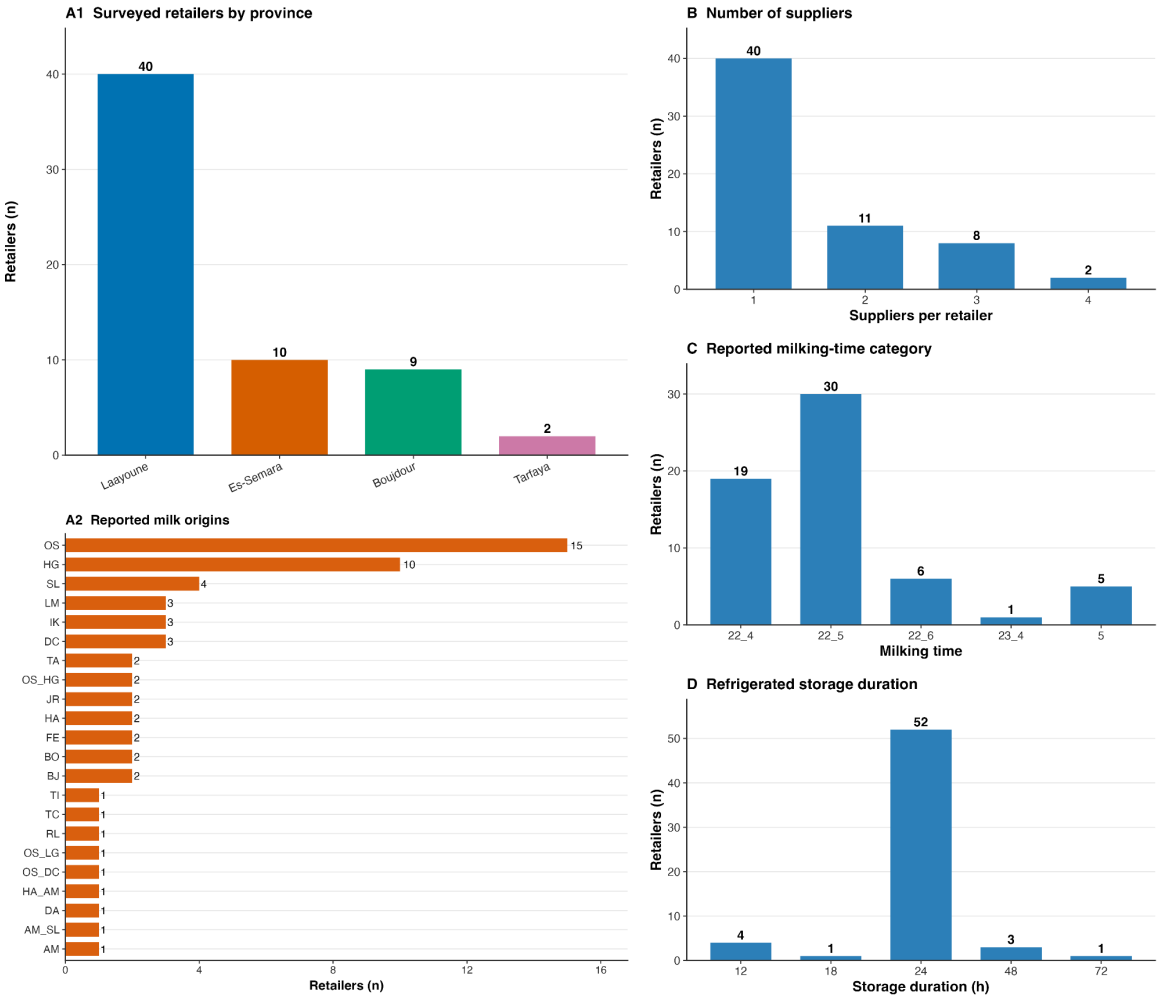

Figure 2. Camel milk retail structure and preservation practices in Laâyoune-Sakia El Hamra. (A) Distribution of surveyed retailers by province and reported milk-origin communes; colours identify provinces and supply origins. (B) Number of suppliers per retailer. (C) Reported milking-time categories. (D) Refrigerated storage duration of raw camel milk at retail. Bars show the frequency of retailers in each category (n = 61).

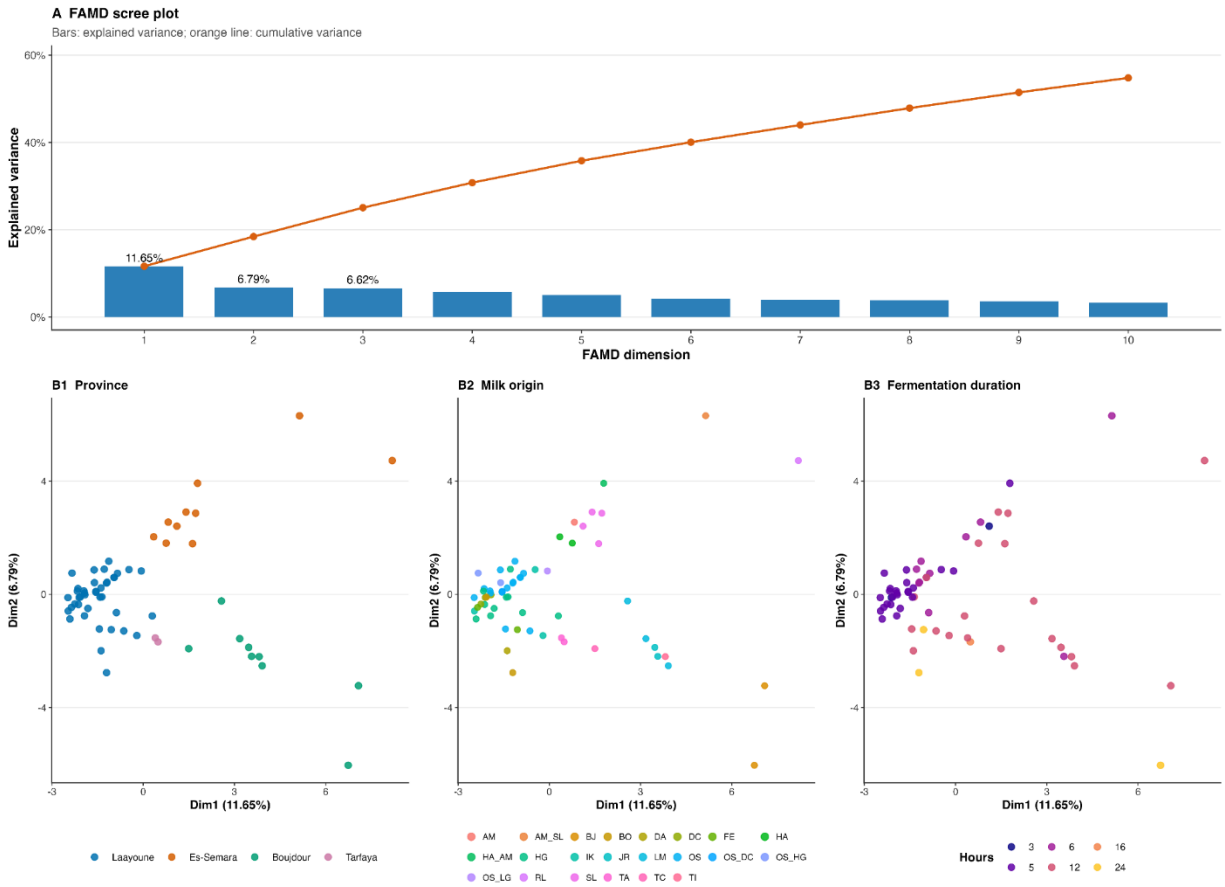

Figure 3. Multivariate structure of retailer practices. (A) Scree plot showing eigenvalues and explained variance from Factor Analysis of Mixed Data (FAMD). (B) Projection of retailer observations on the first three FAMD dimensions; colours distinguish provinces, milk origins and fermentation-profile categories as indicated in the figure legend.

4. Discussion

Our findings highlight the importance of a short supply chain characterised by early morning deliveries, quick chilling and a double preservation strategy with both rapid sale of fresh milk and conversion of unsold milk into the traditional fermented product "Frick." These observations are coherent with the contribution of dromedaries to arid areas by supporting pastoral activities, ensuring food security and adapting to drylands' challenges (Faye et al., 1997; Faye et al., 2001; Amsidder et al., 2024). As there is currently limited formal processing infrastructure for dairy products in Southern Morocco, the retailing practices offer an essential connection between pastoral production and consumer markets. The high demand for fresh camel milk shows that raw milk consumption remains significant in local markets. The dominance of direct sales and semi-formal distribution in the marketing of camel milk in Morocco has already been described. Milk is primarily sold directly to consumers as fresh or traditionally fermented but seldom sold industrially processed (Faye et al., 2001; Alaoui Ismaili et al., 2019).

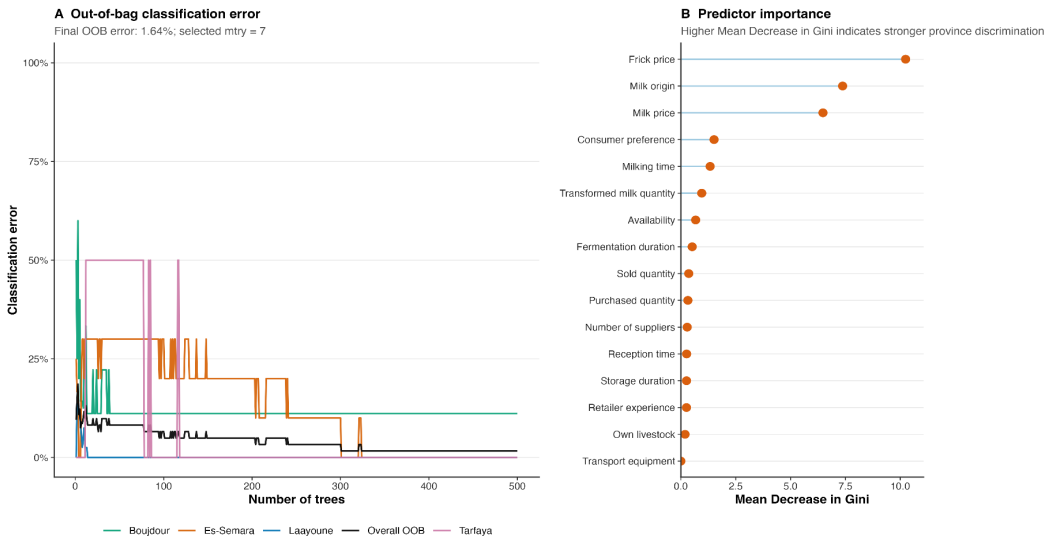

Figure 4. Random-forest province classification. (A) Out-of-bag (OOB) error across trees for the model predicting province from retailer-practice variables. (B) Variable importance based on Mean Decrease in Gini; higher values indicate stronger contribution to province discrimination.

The good quality of raw milk depends heavily on factors such as milking hygiene, transport, storage temperature and duration from milking to consumption. Research on raw camel milk in Morocco highlights the importance of microbiological quality and management practices for assessing safety and market potential (Alaoui Ismaili et al., 2019). Most retailers described fast refrigeration as an important positive aspect. Controlling temperature plays an essential role in maintaining the quality of raw milk because of its impact on microbial activity, physico-chemical properties and shelf life. A recent study on raw camel milk storage assessed the impact of storage temperature and duration on milk quality and underlined the relevance of short holding times and cold-chain management (Wang et al., 2024). Refrigeration at about 4°C and a typical 24-hour window for fresh milk sale could constitute a feasible daily practice to reduce risk in this study. Nevertheless, it is impossible to verify that the cold chain was maintained from milk collection to sale because direct temperature monitoring and microbiological tests were not carried out.

Converting unsold milk into Frick seems to be a regionally tailored strategy with both economic worth and consumer acceptance. Camel milk products can be made more diverse and have a longer shelf life through fermentation. Fermented camel milk is one potential way to preserve and increase value (Hamed et al., 2024). Spontaneous fermentation can be influenced by a number of variables, including the initial microbial load, external temperature, container hygiene, microbiota in the fermentation vessel, and carryover from previous lots. These semi-controlled fermentation parameters could account for the wide variety of fermentation timeframes seen in this study. To evaluate the quality of Frick, pH dynamics, microbial counts, pathogen detection, and sensory analysis are crucial.

The majority of provincial differences in retail practices were explained by the milk's geographic origin and cost-related factors, suggesting that the system is influenced by local milk suppliers,

market size, customer needs, and retailer turnover. Such variation is to be expected in camel milk production, as it depends on several factors affecting milk production, including herd mobility, lactation length, seasonal variation and pastoral resources (Boujenane, 2020; Amsidder et al., 2024). Interventions should therefore not be uniform across the region. Some areas might benefit more from training, cooperative collection and practical preservation advice, while others may require improved refrigeration capacity, traceability and packaging, specifically in larger retail locations.

The low amount of variation captured by the first FAMD axes reveals that retailer profiles are spread over a few weak gradients, as expected in a complex field food system with multiple interacting constraints. Cold-chain management, container hygiene, packaging, sourcing traceability, retailer training and fermented-product control should therefore be addressed jointly. Multivariate results illustrated that no major technical parameter alone drives the retail system.

Our findings stem from a survey designed to identify patterns in multivariate space and are not a substitute for direct testing of milk safety or product quality. One of the main limitations of this work is its reliance on reported practices rather than laboratory confirmation. Recommendations regarding safety, shelf life or standardisation should therefore be cautious. Future research should include sampling of fresh milk and Frick along the chain, recording storage temperature during transport and retail, investigating container cleaning methods and testing pH, acidity, total bacterial counts and relevant pathogens. Such data would allow these survey-based patterns to be transformed into evidence-based critical control points and safer utilisation strategies for camel milk in Southern Morocco.

5. Conclusion

Camel milk retailing practices in the Laâyoune-Sakia El Hamra region were described by surveying all existing 61 retailers. A short supply chain, early morning deliveries, quick chilling, and two parallel preservation pathways (short-term storage for fresh milk and transformation of unsold milk into the traditional fermented product “Frick”) characterise the retail process. Consumer demand focused mostly on fresh milk, while fermented milk is also an important side product. Results from multivariate and classification analysis reveal that there are differences between provinces in terms of retail practices, depending mostly on variables related to the origin and the price of milk and not on fundamentally different preservation approaches.

Based on the results obtained, recommendations are given on how to improve current retailing practices, considering the local sourcing network and market specificities. However, this study has limitations, and results related to product safety should be interpreted carefully. Because this study did not include microbiological, physicochemical or direct hygiene measurements, further studies should combine retailer questionnaires with objective quality assessment, including storage temperature monitoring, hygiene parameters and microbiological and physicochemical tests of fresh and fermented camel milk.

Acknowledgments

This study was carried out within project AS-05/2023, financially supported by the OCP-PhosBoucraa Foundation. The authors thank all staff of DRA of Laâyoune-Sakia Al Hamra, DPA of Es-Semara, ONSSA of the southern regions of Morocco, and ONCA of Laâyoune-Sakia Al Hamra for their support and assistance during the surveys. They also thank all retailers who participated in this study

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