



OPEN ACCESS

EDITED BY

Derradji Harek,
Algerian National Institute for Agronomic
Research INRAA, Algeria

*CORRESPONDENCE

Asma Souissi,
✉ asmasouissi.fr@gmail.com

RECEIVED 27 February 2026

REVISED 30 May 2026

ACCEPTED 15 July 2026

PUBLISHED 06 August 2026

CITATION

Souissi A, Dhehibi B, Baker D, Wane A,
Burkart S and Flintan F (2026) An
exploratory analysis of the Tunisian
dromedary camel value chains for
sustainable development in
arid rangelands.
Pastoralism 16:16487.
doi: 10.3389/past.2026.16487

COPYRIGHT

© 2026 Souissi, Dhehibi, Baker, Wane,
Burkart and Flintan. This is an open-access
article distributed under the terms of the
Creative Commons Attribution License
(CC BY). The use, distribution or
reproduction in other forums is permitted,
provided the original author(s) and the
copyright owner(s) are credited and that
the original publication in this journal is
cited, in accordance with accepted
academic practice. No use, distribution or
reproduction is permitted which does not
comply with these terms.

An exploratory analysis of the Tunisian dromedary camel value chains for sustainable development in arid rangelands

Asma Souissi^{1*}, Boubaker Dhehibi², Derek Baker³,
Abdrahmane Wane⁴, Stefan Burkart⁵ and Fiona Flintan⁶

¹Higher School of Agriculture of Mograne, IRESA - University of Carthage, Zaghouan, Tunisia,

²International Center for Agricultural Research in the Dry Areas (ICARDA), Tunis, Tunisia, ³UNE Business
School, University of New England, Armidale, NSW, Australia, ⁴International Livestock Research Institute
(ILRI), Dakar, Senegal, ⁵International Center for Tropical Agriculture (CIAT), Cali, Colombia, ⁶International
Livestock Research Institute (ILRI), Addis Ababa, Ethiopia

Dromedary camel value chains present significant opportunities for attracting investors and reinvesting in rangeland restoration. Despite declining productivity and limited development of dromedary milk products, the sector remains crucial for its resilience in arid ecosystems and socioeconomic importance in the southern regions of Tunisia. The authors take a reflective approach to explore the potential of dromedary value chains in Tunisia. The study highlights the dual benefits of investing in these value chains, to drive economic development and environmental conservation, by employing a combination of desk review, key informant interviews (n = 11), and SWOT analysis. The sector assessment reveals statistical complexities and fluctuations in milk and meat production. Key informant interviews gathered insights from breeders, processors, traders, policymakers, and experts on challenges, opportunities, and feasibility of investment and rangeland restoration initiatives. The SWOT analysis identified internal strengths and weaknesses in the dromedary sector and external opportunities and threats. Recommendations include modernizing dromedary camel farming (settled, semi-intensive systems) and herding practices (nomadic and extensive pastoralism), transitioning to sustainable breeding and fattening, improving biosecurity and veterinary services, and enhancing feed management and genetic improvement. Strengthening value chains involves investing in processing infrastructure, marketing, product diversification, and structured milk collection networks. Integrated rangeland management includes cultivating fodder crops and protecting vegetation cover. Governance improvements through dromedary breeder associations, stakeholder engagement, and effective regulation are also crucial. Findings may inform policymakers, development agencies, financial institutions, and private investors about the dromedary sector's potential in Tunisia, guide targeted interventions for growth and sustainability, and provide pathways to rangeland restoration. By addressing challenges and leveraging unique capabilities, dromedary value chains can drive economic development, environmental conservation, and social resilience in the region.

KEYWORDS

dromedary value chains, rangeland restoration, resilience, sustainability, Tunisia

Introduction

Arid and desert rangelands in southern Tunisia, encompass approximately 5.5 million hectares, 87% of which are located in arid and desert zones (Gamoun et al., 2018). Desertification and other degradation of rangelands is affecting much of the nation's rangelands, particularly in the arid south where pastoral grazing is the principal land management mechanism (Ouled and Louhaichi, 2017). In this article we examine the potential for the commercial development of one traditional pastoral sector, dromedary camels, to contribute to the restoration of rangelands.

In parallel with these land-use challenges, camel production systems and their associated value chains have undergone rapid transformation at the global scale, with growing interest in camel meat and milk as climate-resilient livestock products and as emerging niche markets in both traditional and non-traditional consuming countries (Boukrouh et al., 2025; Ait El Alia et al., 2025). Recent global assessments indicate that the world camel population has increased steadily over the past decades, surpassing 40 million head by 2022 (FAO, 2024). In Africa, camel numbers have grown particularly rapidly, reaching around 1.5 million head in 2022. Asian herds have expanded more moderately but experienced a marked acceleration after the early 2000s, exceeding one million head by 2022 (Boukrouh et al., 2025). These global trends highlight the rising importance of camels and provide a useful backdrop for analysing the evolution of Tunisia's comparatively small but regionally strategic dromedary sector, underlining the need to understand how national camel systems can evolve to deliver both economic returns and environmental co-benefits in fragile rangeland ecosystems.

The potential for enhanced delivery of benefits from rangelands, both commercial and in non-market environmental goods, is widely acknowledged (Nielsen et al., 2020). A recent discussion of African rangeland regeneration opportunities presented by development of value chains for rangeland products has been presented by Teno (2022). Rationalised camel husbandry practices have been shown to help restore southern Tunisian rangelands while delivering sustainable income to pastoralists (Ouled Belgacem et al., 2019; Frija et al., 2024)). Our exploratory study aims to identify economic opportunities within the dromedary camel value chains, especially regarding rangeland restoration in southern regions of Tunisia. The specific objective is to identify financing mechanisms to mobilize private sector capital to restore rangelands: this includes the profit streams from high-value sustainable dromedary products. Building on recent syntheses of the global camel meat and milk sectors, we narrow the focus to Tunisia, where dromedary herd dynamics and product value chains remain under-documented despite their strategic importance for arid rangelands. By integrating value-chain development with rangeland restoration and sustainability considerations, this study fills an important gap in the literature on camel systems in Tunisia and North Africa.

In this exploratory study, we first present a summary of each of the value chains for dromedary products, focusing on the functions and stakeholders within the chains, and the constraints on their commercial development. Our primary data is collected from a sample of the stakeholders, whose expert views on commercial and rangeland restoration prospects we capture at interview. Our structured presentation of their perceptions of the current

situation, opportunities and challenges, and proposed solutions is synthesised into a SWOT analysis and action recommendations, and identified suitable sources of financial resources.

Tunisian dromedary value chains

An overview of the sector

In Tunisia, estimates of dromedary numbers vary according to data sources and definitions. National livestock statistics report around 56,000–80,000 head, mainly breeding females (80,000 females in 2017), reflecting a long-term decline from approximately 225,000 head in the 1950s, driven by illegal export, low breeding efficiency, social change and limited investment (Jemli et al., 2018). In parallel, FAOSTAT (2024) report a total camel population on the order of 230,000–240,000 head, including all age and sex categories and correcting for under-reporting in national counts (Nouairia et al., 2015). These differences reflect contrasting census methodologies rather than a real 400% biological increase in the national herd. The variability is also discussed by (Faye, 2020), who suggests that discrepancies highlight the complexities and challenges associated with agricultural statistics in the region such as inconsistent individual animal identification and socio-economic transformations affecting herd sizes.

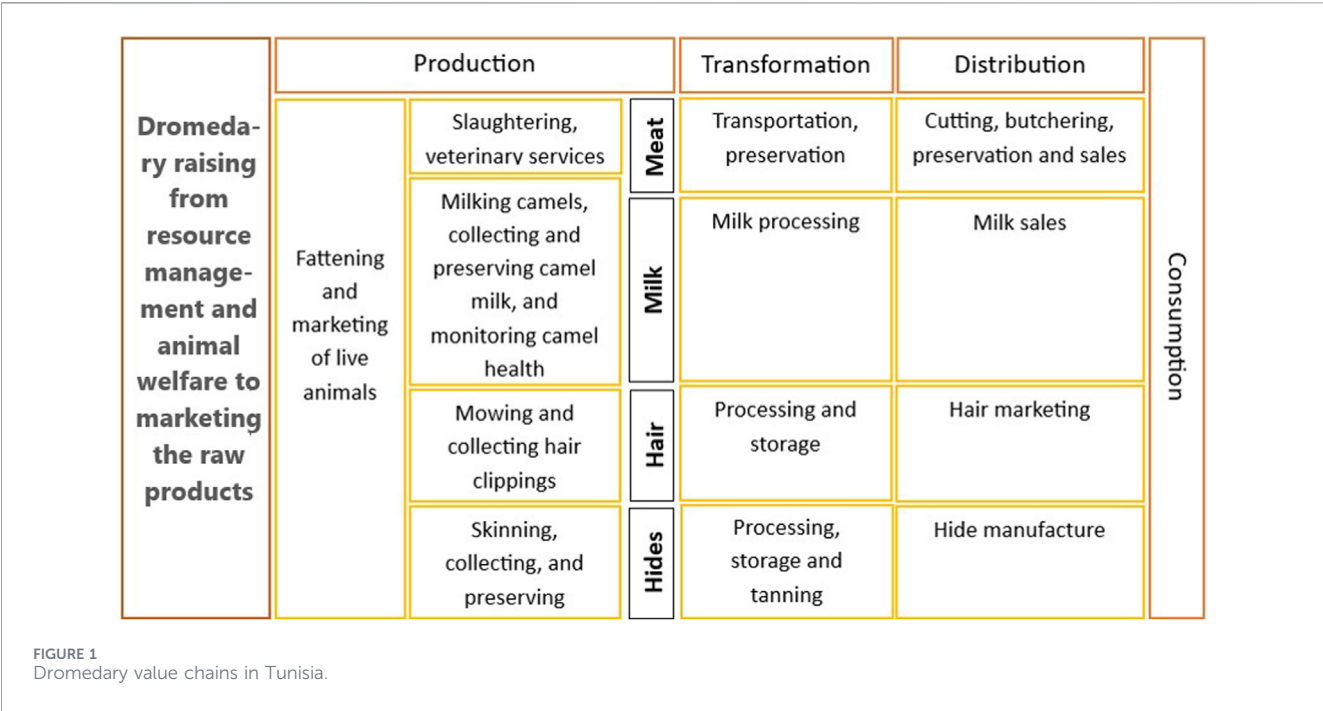
The sector is characterized by a predominantly nomadic and transhumant pastoral system where dromedaries graze on natural pastures. The highest concentrations are found in the southern regions, in areas such as Kebili and Tataouine (Tardif et al., 2014). As the current global camel population is estimated to be 41 million (FAO, 2024), the Tunisian dromedary livestock sector and herding¹ represents a relatively small but regionally important fraction, underscoring both its local socio-economic role (Tardif et al., 2014). These herd and production dynamics are closely intertwined with rangeland conditions, as most Tunisian dromedaries are raised under extensive pastoral systems that depend directly on the availability and quality of natural grazing resources (Ouled Belgacem et al., 2019).

Products include milk, meat, wool or hair, hides, and occasionally dung used as fuel. Processing of dromedary products often occurs informally. Marketing and consumption of dromedary products take place mainly through local markets where live animals, milk and meat are sold within communities and between nearby towns (Figure 1).

Tunisia has also implemented a national strategy (2016–2020) to promote the dromedary sector. This includes providing subsidies for fattening, young female animal management and sector investments. The strategy aims to improve dromedary owners' access to markets, credit and inputs.

Recent studies on dromedary value chains in North Africa highlight that camel milk and meat value chains face issues like low productivity, market accessibility and lack of organization (Najjar et al., 2024; Amsidder et al., 2024). These challenges are intensified by hygiene practices and milk quality issues along the

¹ Herding: Refers primarily to the traditional, often nomadic or transhumant pastoral management of dromedary camels, where herders move camels across rangelands in search of grazing. This system is characterized by low input and extensive grazing.



value chain, with the microbial load increasing from production to the point of sale (Atigui et al., 2023).

In Tunisia, raw dromedary milk generally shows total solids around 11%–13%, fat 2.5%–3.5%, protein 3%–3.5% and a pH close to neutral, values that are consistent with other arid-zone studies and underpin its nutritional and functional appeal (Atigui et al., 2023; Zammouri et al., 2024). However, recent work in southern Tunisia indicates that, although this basic composition remains stable along the chain, mesophilic counts, coliforms, *Staphylococcus aureus* and acidity frequently exceed acceptability thresholds at retail when hygiene and cold-chain conditions are inadequate (Atigui et al., 2023). These microbiological levels often surpass the maximum total aerobic counts and indicator-organism limits set for raw milk by Tunisian dairy regulations, indicating that much camel milk traded through informal channels does not comply with national safety standards (Atigui et al., 2023). This emphasises needs for improved quality control measures and better infrastructure for milk collection and storage.

Comparing these findings with the situation in Morocco, a similar pattern emerges. Dromedary systems in Morocco also face challenges related to value chain development, with traditional practices and mobility sometimes seen as obstacles to modernization (Amsidder et al., 2024). However, there is also growing demand for camel products from the urban middle class, creating niche market opportunities (Amsidder et al., 2024). This suggests that strategies to improve market access and promote value-added dromedary products could be particularly effective in North Africa.

Dromedary milk

Tunisia produces around 15,000 tons of camel milk annually (Jemli et al., 2018). However, official reports indicate that only about

1,000 tons of this production are documented, suggesting a substantial gap between actual production and reported figures, according to the National Observatory of Agriculture. This under-reporting reflects the predominance of informal and household-level consumption, and complicates efforts to characterise the contribution of camel milk to national livestock output. Meanwhile, camel milk has attracted significant global interest in recent years due to its purported health benefits, some of which remain scientifically unproven (Muthukumaran et al., 2022). Dromedary milk is transformed into products such as fermented milk, butter and cheese. Commercial facilities for pasteurization and processing are limited (Alary et al., 2021).

Several larger scale dairy dromedary farms have been established in selected governorates, with both raw and pasteurized milk being produced and marketed through different channels. However, like other North African countries, Tunisia's dromedary camel dairy sector faces challenges like milk seasonal shortages due to herd mobility and limited collection volumes. This hinders the consistent operation of dairy plants. Additionally, inadequate producer co-ordination—particularly weak farmer cooperatives - hinder collective bargaining power and limit access to markets and essential services (Alary et al., 2021).

The dromedary dairy product supply chain remains largely unexamined and there have been few studies evaluating the quality and safety of milk available for consumers (Atigui et al., 2023). Traditionally, dromedary camels are hand-milked for household use, resulting in inconsistent quality and quantity for urban markets. However, over the past 10–15 years, production has seen significant advances, including the introduction of machine milking in countries like the UAE, Saudi Arabia and Tunisia (Nagy, 2016). Small-scale farms in Australia, Europe and the USA have adopted this technology. The intensification of the dromedary camel dairy industry worldwide prompted increased research and

development in areas such as dromedary camel lactation, nutrition and management (Nagy et al., 2022).

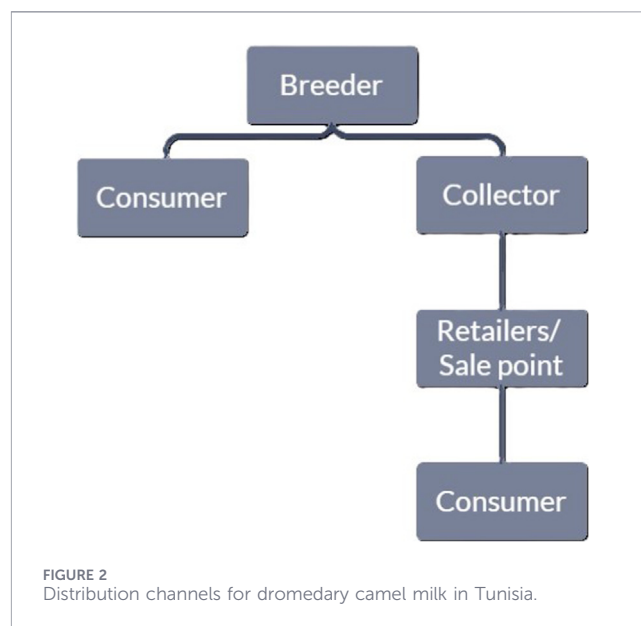
Recent research in Tunisia has focused on assessing the milk production capacity and composition of Tunisian dromedaries, with the goal of developing improved feeding strategies and breeding² programmes to enhance milk output (Ayadi et al., 2009; Chamekh et al., 2020; Khaldi et al., 2022). Despite these efforts, dromedary camel milk has not been fully integrated into the Tunisian domestic market as has occurred in countries such as the United Arab Emirates and Saudi Arabia. Offline distribution channels, referring to traditional physical means of distribution, account for over 80% of global revenue in the dromedary milk sector (Atigui et al., 2023). Consumers tend to buy raw milk directly from farms or retailers due to its short shelf life and daily consumption needs (Bekele et al., 2021; Cheikh Ismail et al., 2022). In Tunisia, there are two primary sales channels for dromedary camel milk (Figure 2). The first involves direct sales to consumers along roadsides, where raw or fermented milk is sold without formal packaging or hygiene controls, often at competitive prices. The second channel consists of sales through local market retailers, also lacking formal packaging.

Dromedary meat

National statistics indicate that dromedary meat production has fluctuated over the past 2 decades, with a marked decline in controlled slaughter, illustrating both the sector's vulnerability and the importance of informal marketing channels (Jemli et al., 2018; Najjar et al., 2024). Meat is mainly consumed locally, with traditional preservation methods like drying and salting the most common practices. Slaughter typically occurs in small local abattoirs. The dromedary meat value chain involves breeders, butchers, traders and consumers is sketched in Figure 3. It has two main marketing channels: the traditional and integrated (Najjar et al., 2024). Dromedary meat distribution involves short and long supply chains, with common direct transactions between breeders, retailers and intermediary traders. However, a significant portion of dromedary meat (around 94%) remains outside controlled slaughter systems, highlighting challenges to transparency and public health (Najjar et al., 2024). These characteristics are consistent with broader patterns described for camel meat sectors in many producing countries, where informal marketing, limited cold-chain infrastructure and weak quality control remain key constraints along the supply chain (Boukrouh et al., 2025).

Multifunctional roles and secondary value streams of the dromedary

Beyond meat and milk, the dromedary contributes to several secondary value streams and multifunctional roles within local livelihoods. Dromedary fibre is used in weaving and crafting, while hides can be processed into leather goods, although these uses remain relatively limited and under-developed in Tunisia



(Selmi et al., 2017). Camel-based cultural products, including camel rides and associated cultural performances, have also become important attractions in tourism circuits in some regions, illustrating how dromedaries contribute simultaneously to income diversification, cultural heritage valorisation and territorial image (Nagy, 2016; FAO, 2024). The dromedary carries strong cultural significance in southern Tunisia, where it is closely associated with Bedouin identity, nomadic traditions and oasis life (e.g., Douz and other Saharan towns). Camels feature prominently in regional festivals such as the International Sahara Festival of Douz, through activities like camel races and caravans, where the animal symbolises endurance, mobility and social status. This cultural capital reinforces local attachment to camel husbandry.

Dromedary production and rangelands

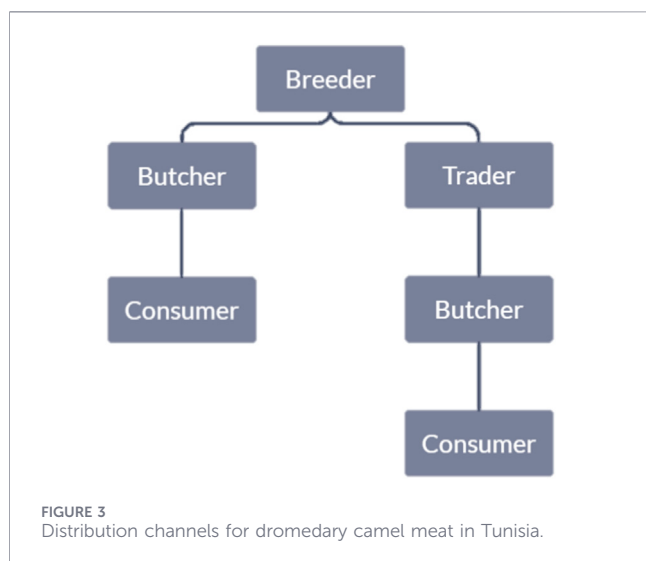
Production systems

Although dromedary herding in Tunisia is not on as large a scale as other livestock sectors, it remains an integral part of the cultural fabric and economy of southern Tunisia. According to Alary et al. (2021), the dromedary sector's social network is more developed upstream than is the case for other countries. This includes strong links between vets, feed suppliers, associations, the administration and researchers.

Faye (2013) underscores the necessity of integrating dromedary rearing³ into a sustainable economic framework, particularly in the face of increasing urbanization and demand for dromedary products. Faye highlights the potential for dromedary byproducts to alleviate the pressure on water resources, suggesting that

² Breeding: The controlled reproduction of camels focusing on genetic selection, mating, and improving herd traits for productivity (e.g., milk yield, meat quality). Breeding can occur under both herding and farming systems.

³ Raising/Rearing: General terms describing the care and management of camels from birth to maturity, encompassing nutrition, health, and growth. These terms overlap with herding and farming but emphasize the developmental stage of the animals.



innovative feeding strategies could enhance sustainability within the dromedary farming⁴ system.

Building on this foundation, Selmi et al. (2018) delve into the socioeconomic dynamics of dromedary camel herding in southeastern Tunisia, particularly in the context of climate change and resource scarcity. Their study illustrates how such herding serves as a critical response to societal challenges, including desertification and rural poverty. The authors advocate for a nuanced understanding of camel farming's role in promoting food security and sustaining rural populations. The PROCAMED⁵ project is highlighted as a strategic initiative aimed at enhancing dromedary farming practices, thus reinforcing the economic viability of this sector amidst environmental challenges.

Further advancing the discourse (Yakubu et al., 2022), focus on the need for capacity building among camel herders to enhance productivity and profitability. Their review emphasizes the importance of empowering local herders through improved management practices, healthcare and decision-making skills. The authors argue that successful conservation and production of camel populations hinge on the active involvement of herders, who must have access to the necessary resources and knowledge. This approach not only fosters a sense of ownership among herders but also contributes to the broader goals of food security and economic development.

Rangeland management and development of dromedary products

There is a growing recognition of the economic importance and resilience of camel pastoralism in the face of climate change, evidenced

by increasing herd sizes and emerging dairy plants (Naji and Kandeel, 2024). Camel herding is no longer viewed as a subsistence activity but as a potential driver of territorial development in arid regions (Amsidder et al., 2024). The sustainable development of the sector requires balancing camel demography with environmental capacity, preserving genetic diversity, developing alternative feeding systems and promoting high-value products (Faye, 2013; Faye et al., 2014; Jaouad, 2016).

Although camels have historically contributed to combating desertification and have a small ecological footprint, intensification may alter their impact on the environment (Faye, 2020). Studies in northern Kenya have demonstrated that environmental factors like climate variability and drought significantly influence the sustainability of camel milk value chains (Machan et al., 2022a). A study in Saudi Arabia found that most camel owners have little practical knowledge of herd management and environmental sustainability (Cheikh Ismail et al., 2022). Therefore, as camel farming adapts to meet growing demands, integrating sustainable practices and addressing knowledge gaps will be crucial to ensuring long-term environmental benefits (FAO, 2024).

Policies that promote the use of agriculture-based feed resources can help reduce the reliance on rangelands, which are increasingly threatened by climate change (Rjili et al., 2023). Faye emphasizes the importance of balancing economic growth with environmental stewardship, noting that the intensification of dromedary production must consider its ecological impacts and the social dynamics of dromedary pastoral communities.

The investment environment and stakeholder engagement

Improvements in efficiency and market access require an investment in infrastructure, including roads, storage and markets (Thabet, 2024; Harek et al., 2022). Research and development are critical for increasing productivity, particularly with respect to genetic diversity and feed supplementation (Harek et al., 2022; Kamili et al., 2020). Supporting smallholders through training, credit and market links remain an essential element in engaging smallholders equitably in the sector (Christian et al., 2024; Hidayati et al., 2021). These investments can address structural barriers, strengthening systemically resilient value chains.

Investors face several potential risks, including sanitary risks such as diseases that reduce production and cause dromedary mortality. There is minimal enforcement of regulations in the informal dromedary milk supply chain in Tunisia (Eckstein et al., 2021; Atigui et al., 2023). This poses food safety risks. Economic risks include lower farm gate milk prices and decreases in dromedary herds. The absence of comprehensive legislation and regulations, the vulnerability of the sector to global environmental and market changes, and the population exodus all pose significant risks to investors. Factors that further exacerbate these risks are internal conflicts, low competitiveness of local products, low breeding productivity, lack of quality grazing land and fodder resources, drought and the absence of a legal framework for collective lands.

Existing studies on camels in Tunisia and North Africa mainly address herd management, milk production/composition or specific dairy and meat chain segments, usually from a technical or economic angle. In contrast, there is little empirically grounded

4 Farming: Denotes more settled, semi-intensive, or intensive camel production systems involving greater management inputs, infrastructure, and controlled feeding. Camel farming is often commercial in nature and practiced near urban or peri-urban areas.

5 Promotion of the innovating camel systems and of the local camel value chains for a sustainable management of the Saharan territories. The project - procamed.cirad.fr

work that integrates stakeholder perspectives on governance, value capture and environmental dimensions of the dromedary value chain in relation to rangeland systems. This study responds to that gap by offering an exploratory, SWOT-informed analysis of the Tunisian dromedary value chain based on expert and practitioner interviews, thereby adding new evidence on how actors understand its economic, social and environmental roles and where they see leverage points for more sustainable development in arid rangelands.

Materials and methods

Research questions

Our analysis is guided by three exploratory research questions. First, how and to what extent does increasing market demand act as an impetus for investment in dromedary milk and meat value chains in southern Tunisia? Second, in which ways are these value chains underdeveloped in terms of technology, engagement of producers and youth, investment and policy support? Third, how do stakeholders perceive the links between value chain development and environmental sustainability, including rangeland condition and restoration?

Key informant interviews

The absence of a consistent and reliable dataset on Tunisian camel production and value chain variables limits the analysis and available inference for projections of the sector's future. In particular, there is sparse evidence upon which to base an analysis of commercialisation and the interaction of the sector with key policy and societal goals such as economic development and the restoration of natural resources such as rangelands. We then take the approach of Key Informant Interviews, employed as a qualitative technique since its early description by Marshall (1996), and applied in a range of data-poor research contexts such as long range national agricultural strategies in the face of climate change, indigenous knowledge systems, forest and community interactions, and pastoralists' rangeland management (Lelenguyah et al., 2021; Ashton and Bradshaw, 2023; Bonye et al., 2023; Mekuria et al., 2023; Yeleliere et al., 2023). We present the results of these interviews and synthesise them within a Strengths, Weaknesses, Opportunities and Threats (SWOT) framework (Helms and Nixon, 2010) to organise our analysis and frame the main conclusions.

Sampling and data collection

A sample of informed value chain participants was assembled for interviews. The sample consisted of eleven purposively selected experts offering diverse stakeholder perspectives. Researchers and development specialists comprised five participants, reflecting our emphasis on scientific expertise. Dromedary breeders (three participants) and government officials (three participants) were also represented. For confidentiality reasons, we did not collect personally identifiable socio-demographic details such as exact age, gender or place of residence. The analysis therefore focuses on respondents' professional roles and expertise rather than on individual socio-demographic characteristics.

This KII sample was purposively selected to capture information-rich perspectives from breeders, government officials and researchers positioned at different points in the dromedary value chain. Given the exploratory and qualitative nature of the study, the sample size ($n = 11$) was designed to prioritise depth and diversity of insights over statistical representativeness, in line with recommended practice for key informant interviews. As such, the findings should be interpreted as an in-depth, hypothesis-generating diagnosis rather than a comprehensive representation of all value chain actors in Tunisia. Interviews comprised six sections: (i) the background and current situation section evaluated stakeholder roles and the current status of the dromedary camel value chains; (ii) the opportunities and challenges section identified potential growth areas and obstacles and strategies for overcoming them; (iii) the sustainability and conservation section focused on the environmental benefits of the dromedary value chains and existing sustainable practices; (iv) the policy and investment section highlighted supportive policy measures, investment strategies and potential risks for investors; (v) the social impact section assessed how dromedary value chains affect local livelihoods and any social challenges that arise; and finally: (vi) the future section invited respondents to articulate their vision for dromedary camel value chains in Tunisia. Qualitative data were collected through face-to-face, semi-structured KIIs. Each interview lasted approximately 20–30 min and was completed on paper during the interview. The interview guide covered the sections mentioned above, and the responses were thematically coded in Excel using an inductive approach. Initial codes were derived from recurring ideas and subsequently grouped into broader themes and SWOT categories according to whether they reflected internal or external factors.

Results and discussion

Stakeholder perceptions

The key informant interview analysis revealed systemic disparities in engagement across participant groups, with researchers and government officials dominating sustainable development initiatives, policy formulation and support mechanisms, while producers and producer organizations exhibit limited participation in conservation and market access and total disengagement in value addition. These asymmetries reflect a fragmented engagement ecosystem, where researchers and policymakers dominate high-level initiatives while producers face exclusion from economic and environmental decision-making. These disparities align with institutional coordination challenges highlighted by Najjar et al. (2024), particularly the lack of structured dialogue between producers and institutional actors.

The findings underscore critical gaps in integrating grassroots actors into economic and environmental decision-making. Addressing these disparities requires participatory workshops to co-design inclusive policies, capacity-building programmes for producers in market analytics, conservation practices, and policy evaluations to align institutional

frameworks with on-ground realities, as encouraged by Faraz et al. (2021).

Such interventions could foster equitable engagement, bridge the policy-practice divide and advance integrated strategies for sustainable development.

According to the majority of interviewees, dromedary value chains in Tunisia are characterized by significant challenges, including low productivity and poor market access, while there is stagnation, reflecting systemic inefficiencies in governance and market integration. This aligns with findings from Tunisia's dromedary meat sector analysis, which identifies fragmented institutional coordination and weak relational flows between actors (e.g., breeders, traders, policymakers) as drivers of marginalization and clandestine practices (Najjar et al., 2024). Similarly, the camel milk sector faces critical barriers in terms of food hygiene, limited government support and quality control, exacerbating market access issues (El Alia et al., 2025). In addition to hygiene and cold-chain weaknesses, concerns about adulteration of camel milk with bovine milk or water emerged as an important barrier to consumer trust and to the formalisation of the Tunisian camel milk market. This is in line with recent studies showing that raw camel milk quality in southern Tunisia tends to deteriorate along the value chain in the absence of robust quality control systems, limiting access to higher-value outlets (Atigui et al., 2023). The deployment of simple *in situ* authenticity tests at milk collection points, such as portable near-infrared spectroscopy devices or lateral-flow immunoassays adapted to camel milk, would facilitate rapid detection of dilution or substitution, underpin quality-based payment schemes and, ultimately, help breeders secure a stable share of the value generated by camel milk (Ait El Alia et al., 2025; Ait El Alia et al., 2024; Chu et al., 2023).

These structural gaps reflect participants' concerns, underscoring the need for integrated strategies to address productivity and governance deficits.

Table 1 summarizes participant perceptions of Tunisia's dromedary sector, evaluating aspects like potential and challenges. It includes statements, perceptions classification as "High" or "Low," indicating whether participants generally agree or disagree with each statement and finally rankings to highlight key concerns and priorities.

The analysis of participant perceptions reveals a nuanced understanding of Tunisia's dromedary camel sector, balancing confidence about available potential with critical challenges. Support is the dominant (highest ranked) concern, and addressing limited processing capacity and market access is widely perceived as essential for sector viability. This aligns with evidence suggesting structural weaknesses, such as poorly organized marketing regulations and smuggling problems that weaken value chain efficiencies (Jemli et al., 2018).

Value chain fragility was a second concern. Participants highlighted declining traditional herding practices and youth disengagement, while also emphasizing the need for innovation and investment to modernize practices and attract younger generations. This reflects broader tensions between preserving cultural heritage and adapting to urbanization pressures, particularly as peri-urban dromedary farming disrupts historical nomadic-sedentary dynamics (Djenane and Aider, 2024).

Despite these challenges, unexploited potential and relative neglect compared to other livestock suggest participants recognize the unique role of dromedary camels in arid regions. However, skepticism persists about income generation and the growth of milk production. This is in contrast with studies showing that dromedary-based activities accounts for 79% of household income in southern Tunisia (Tardif et al., 2014). Moreover, camel milk commands a significantly higher market price than cow milk in the region (sometimes up to six times greater) indicating promising profitability within the dairy value chain, even though precise revenue data per value chain actor remain scarce (Letaief and Bedhiaf-Romdhani, 2022). The apparent disconnect between perceptions and documented economic contribution may arise from the irregular distribution of benefits across stakeholders and underdeveloped market linkages that limit access and value capture by producers and intermediaries (Selmi et al., 2017; Najjar et al., 2024). The coexistence of high consumer prices for camel milk and respondents' perception of "low income generation" observed in this study is consistent with recent analyses of camel milk economics in Tunisia and other North African contexts. In arid production systems, camel milk is structurally expensive to produce because feed, labour and veterinary inputs represent a large share of the cost per litre, so that profit margins remain highly sensitive to feed price volatility even when retail prices are relatively high (Faye et al., 2025; Tidjani et al., 2025). At the same time, weak collection and processing infrastructure, small-scale herds and predominantly informal marketing channels limit the volumes that can be sold and reduce producers' bargaining power, allowing traders, transporters and retailers to capture a substantial share of the value added along the chain (Chamekh et al., 2020). These structural features help explain why stakeholders can simultaneously report a high market price for camel milk and only modest improvements in household income. The lowest-ranked perceptions (awareness of economic and environmental value and meat market development) highlight critical gaps in promoting dromedaries' resilience as an advantage (Djenane and Aider, 2024) and diversifying beyond traditional products.

Opportunities and challenges

To provide insight into the dromedary value chains in Tunisia, participants' views on the potential paths for growth and the existing obstacles are presented in Table 2. The table combines findings regarding prioritized opportunities for development and key challenges and constraints hindering the sector's progress. The data allows for a comparison of factors driving growth and those requiring immediate attention for effective intervention.

The analysis of opportunities within the dromedary value chains reveals several insights. Participants highlighted increasing demand for dromedary products as the most significant opportunity, emphasizing strong market potential. There is a growing demand for camel meat in the Arab world and this could be leveraged to boost local production and trade (El-Seretty, 2014). Other economic opportunities include the development of short value chains and potential subsidies for meat and milk, rated as an average priority, likely seen as a supportive policy to encourage production but not as a top driver compared to demand growth.

TABLE 1 Key informant perceptions about the current situation of the dromedary sector.

Statements	Perception	Rank across all participants
The dromedary sector holds significant untapped potential. Demand for camel products is growing	High	3
Dromedary camel raising is providing additional income for farmers in southern Tunisia	Low	6
The sector needs support to overcome challenges like limited processing capacity and market access	High	1
There is growing awareness of economic and environmental value	Low	8
Traditional herding practices are declining and young people are not interested	High	2
The sector needs innovation and investment to revitalize	High	2
Compared to other livestock sectors, dromedary husbandry receives less attention and support	High	4
Dromedary milk production is showing promising growth	Low	7
The meat market remains underdeveloped	Low	5

Source: Authors elaboration based on the key informant interview results.

The adaptability of dromedaries to local climatic conditions was seen by participants as the most significant advantage. Singh et al. (2023) indicated that camels thrive in arid environments, making them resilient to climate variability, which is essential for sustainable livestock production. Other environmental opportunities recognised were the lack of competition with other livestock and deferred grazing practices.

Participants also highlighted the importance of strategic interventions like subsidies, efficient grazing practices and market access to unlock further potential. Amsidder et al. (2024) support these results and agree that dromedary camel value chains present significant economic and environmental prospects driven by increasing demand and adaptability.

The analysis of challenges reveals participants' perceived barriers to development. The most significant challenge is low productivity, particularly in milk yields, which underscores the need for targeted interventions to enhance production efficiency. However, environmental degradation of natural pastures is another major issue as it directly affects grazing resources and camel health. Additionally, the lack of a structured camel milk value chain and insufficient investment and organization were each highlighted by respondents as obstacles to growth, emphasizing the need for financial and structural support to unlock the sector's potential.

Other challenges include a reduction in the number of skilled herders, which raises concerns about herd management and animal welfare, and sector sustainability. Market accessibility remains a notable issue, with logistic difficulties hindering producers' ability to reach distant marketplaces. Additional cited constraints include milk conservation in hot weather, the extensive nature of production systems, low productivity and camel diseases. All these are perceived as contributing to value chain inefficiencies. Finally, limited genetic diversity among dromedaries was identified as a concern for long-term sustainability and adaptability.

Beyond the national context, these perceptions are consistent with international evidence on camel milk value chains. In the United Arab Emirates, camel milk has been progressively industrialised and positioned as a premium functional food, supported by pasteurisation, product diversification and strong branding, which facilitates access to urban markets and health-conscious consumers (Cheikh Ismail et al., 2022). In Morocco,

recent initiatives aim to structure camel milk collection and processing and to promote pasteurised products in peri-urban markets, illustrating a transitional pathway from informal, medicinal uses towards more formalised value chains (Ait El Alia et al., 2023). Compared with these examples, and with FAO/Codex work towards an international standard for pasteurised camel milk and a more integrated global camel milk industry, the Tunisian sector remains largely informal, with minimal pasteurised volumes and weak integration into modern dairy markets, which confirms participants' concerns about the absence of a structured camel milk value chain and limited investment in processing and quality upgrading.

These market and processing constraints are also shaped by institutional and governance factors that affect sustainable camel value-chain development and rangeland restoration. Land tenure insecurity and fragmented responsibilities among institutions can weaken incentives for collective rangeland management and reduce the effectiveness of restoration efforts (Laâbar, et al., 2024). In arid regions, sustainable camel systems depend not only on technical and market improvements but also on coordination among livestock, environment, forestry, and local development institutions (Salmi et al., 2024). Collective governance mechanisms, including pastoral user agreements and locally negotiated grazing arrangements, may help improve compliance and reduce conflicts over access, but their effectiveness depends on institutional recognition and feasible monitoring capacity at the local level (Machan et al., 2022b).

Proposed solutions

Solutions identified by participants to low animal productivity include conventional breeding, feeding and improved production systems including animal health (Table 3). These solutions are linked to rangeland restoration for animal health and nutrition. Further recommendations appear for improved market access and co-ordination of value chains including collection sectors (for milk) and marketing campaigns both generic and to promote differentiated products. Participants notably called for longer term solutions both in terms of infrastructure (water sources, marketing

TABLE 2 Opportunities and challenges in the dromedary value chains identified by interview participants.

Opportunities		Priority assigned
Economic	Growing demand	High
	Development of short value chains	Average
	Camel meat has a promising future	Average
	Milk subsidy	Average
Environmental	Adaptability of dromedaries	High
	Lack of competition with other animals	Average
	Delayed grazing	Average
Others	Others (attractive prices, large underutilized grazing areas)	Low
Challenges		Priority assigned
Low productivity (milk yield)		High
Market accessibility		Low
Degradation of natural pastures		High
Decrease in the number of qualified herders		Average
Other constraints (milk conservation in hot weather, low productivity, extensive production systems, camel diseases)		Low
Lack of a structured dromedary milk value chain		High
Lack of investment and organization		High

Source: authors elaboration based on the key informant interview results.

facilities such as collection centres) and human capital in terms of herders' skill development and a concerted long term effort in sector research.

Sustainability and conservation contribution

Turning to environmental conservation and rangelands restoration, Table 4's results suggest a variety of opinions on the role of dromedary value chains. The perception of dromedary owners' associations and organizations and public-private partnerships providing important rangeland restoration opportunities indicate strong support for community-based and opportunistic forms of resource management. However some respondents expressed concern about the more specific dimensions of environmental sustainability. The findings indicate moderately positive perceptions of contributions to ecotourism, to cultural heritage, and to value addition and market access. These results suggest participants' awareness of the potential for these value chain-related to contribute to conservation objectives, based on economic potential.

Perceptions were significantly lower ranked for contributions to soil health, fossil fuel reduction, biodiversity enhancement and reduced grazing pressure. This pattern suggests that respondents currently prioritise income stability and market access over regulating ecosystem services, a tendency that has also been observed in other rangeland systems (Morizet-Davis et al., 2023; Sharafatmandrad and Khosravi Mashizi, 2021). While stakeholders recognise some potential for camel farming to contribute to sustainability, realising this

potential will depend on targeted interventions and incentives that make improved grazing management, soil health investments and lower fossil fuel reliance compatible with breeders' short-term livelihood objectives. In this sense, results point to the potential for a strengthened camel value chain, under appropriate policy and governance conditions, to contribute indirectly to rangeland restoration rather than demonstrating this effect empirically.

These observations resonate also with broader concerns about the transition from traditional extensive camel herding to more intensive systems and the potential environmental consequences (Faye, 2013).

Current sustainable approaches

Interviewees provided multiple perspectives on sustainable approaches to camel value chains. These offer a multi-tiered view of sustainable dromedary herding methods, with a focus on economic strategies and environmental considerations related to value chain improvements and best practices for management. Advocated policy initiatives include financial support for sustainability projects, and research. Participants recognise the dromedary's role as an ecosystem service. Upgrading the dromedary milk value chain by value adding activities such as processing milk into cheese, is one approach to establishing economic sustainability as a basis for maintaining ecosystem services. In addition, key herd management practices advocated include improved herd management, effective

TABLE 3 Proposed solutions to key challenges in the dromedary value chains.

Challenge	Proposed solutions
Low productivity (milk yield)	1. Genetic improvement: Focus on genetic selection and breeding programmes to enhance milk yield 2. Improved feeding and nutrition: Develop and promote quality fodder; valorize agricultural byproducts (e.g., date palms as feed) 3. Intensified production systems: Promote intensive practices; provide subsidies and facilitate credit access for intensification
Market accessibility	1. Strengthen market links: Improve connections between producers and markets 2. Establish collection centers: Create service and milk collection points in rangelands 3. Demand creation: Raise awareness and promote dromedary products
Degradation of natural pastures	1. Rangeland rehabilitation: Restore degraded pastures 2. Sustainable grazing management: Implement effective and participatory grazing practices 3. Water source development: Create local focal water points
Decrease in the number of qualified herders	1. Shepherd training programs: Train new breeders and herders, emphasizing youth involvement and encouragement
Other constraints	1. Process upgrading: Improve efficiency, standardization (quality), logistics (reduced time/cost) and capacity across the value chain 2. Product diversification: Introduce new products and improve existing ones 3. Value chain integration: Enhance coordination among stakeholders 4. Health monitoring: Implement effective animal health programmes
Lack of a structured camel milk value chain	1. Stakeholder engagement: Increase awareness and involvement 2. Research application: Exploit existing research results
Lack of awareness among herders	1. Market information dissemination: Provide herders with information on market demands and opportunities
Lack of investment and organization	1. Breeder support programmes: Provide support, training and encouragement to breeders 2. Strategic sector development: Pursue a comprehensive sector development strategy

TABLE 4 Perceptions of dromedary value chain contributions to environmental conservation and rangeland restoration.

Category	Specific contribution	Perception	Rank across all participants
Sustainable grazing	Reduced grazing pressure	Low	10
	Improved soil health	Low	11
	Control of invasive species	High	5
	Reduced fire risk by consuming dry vegetation	Low	12
Resource management	Efficient water use	Low	9
	Reduced reliance on fossil fuels	Low	13
	Promotion of biodiversity	Low	8
Economic incentives	Value addition and market access	High	6
	Ecotourism and cultural heritage	High	2
Synergies	Integration with reforestation efforts	High	4
Investment in rangeland restoration	Private initiatives	High	7
	Private–public partnerships	High	3
	Camel organizations	High	1

Source: Authors elaboration based on the interview results.

monitoring for health, and the performance of nutritional adjustments such as forage deferment and diet supplementation. Together, these point towards a holistic approach to sustainable camel herding that considers ecological, economic and animal welfare elements.

Policy interventions for sustainable dromedary value chains

Findings indicate several policy interventions' being crucial to dromedary value chain growth and sustainability. These extend to

support for genetic improvement, including focus on importing high-yield dairy breeds and investing in developing locally adapted, improved breeds. Advocated public goods' provision include co-ordinating and improving seasonal mobility planning, respecting rangeland carrying capacity and enforcing grazing exclusion areas; and such market incentives as grazing fees to promote responsible grazing. Institutional coordination is also widely promoted, particularly by using community-based organizations (CBOs) such as dromedary breeders' groups, and empowering them to manage herds and grazing lands with greater flexibility in rangeland governance. Public-private partnerships are also proposed, to leverage investment strategies, improve market access and implement production improvement and infrastructure provision such as water points: with many benefits in terms of resilience of the nascent value adding activities. Lastly, such a transformation requires clear legislation and education for both value chain actors and supporting service providers in the public and private sectors.

Investment strategies for rangeland restoration

Interview participants maintained the essential nature of the restoration of pasture, mobilization of hydraulic resources, and promotion of collective action through farmer organizations and collective entrepreneurship. Practical extensions included strengthening income-generating activities to ensure cash availability for value addition and value chain co-ordination, such as being able to pay guards for administering pasture rest periods.

In this case study, the contribution of value chain profits to rangeland restoration is a prospective pathway rather than an observed practice. Potential mechanisms include earmarking a share of revenues from value-added camel products into locally managed pasture funds and developing payments for ecosystem services or targeted subsidies that reward restoration-oriented grazing practices. These priorities align with the literature calling for participatory and ecosystem-based approaches to sustainable land management that balance ecological conservation with socioeconomic development (Qureshi, 2024). Economic interventions that incentivize sustainable practices, including payments for ecosystem services or subsidies, have been identified as an enabler of sustainable land management practices (Sanz et al., 2017). By providing economic incentives, these measures can help create a positive investment climate for rangeland development (Liniger et al., 2011). The development of milk collection circuits and the promotion of meat consumption, for example, are identified as multi-functional land-use systems, which means they maximize nutrient cycles by combining crop production with livestock production, resulting in a balance of productivity and reduced risk for environmental degradation (Liniger et al., 2011). Finally, collective entrepreneurial pursuits using farmer organizations continue to promote the decentralized governance models in decision-making, which some researchers have shown to empower local communities (Sanz et al., 2017).

Study limitations

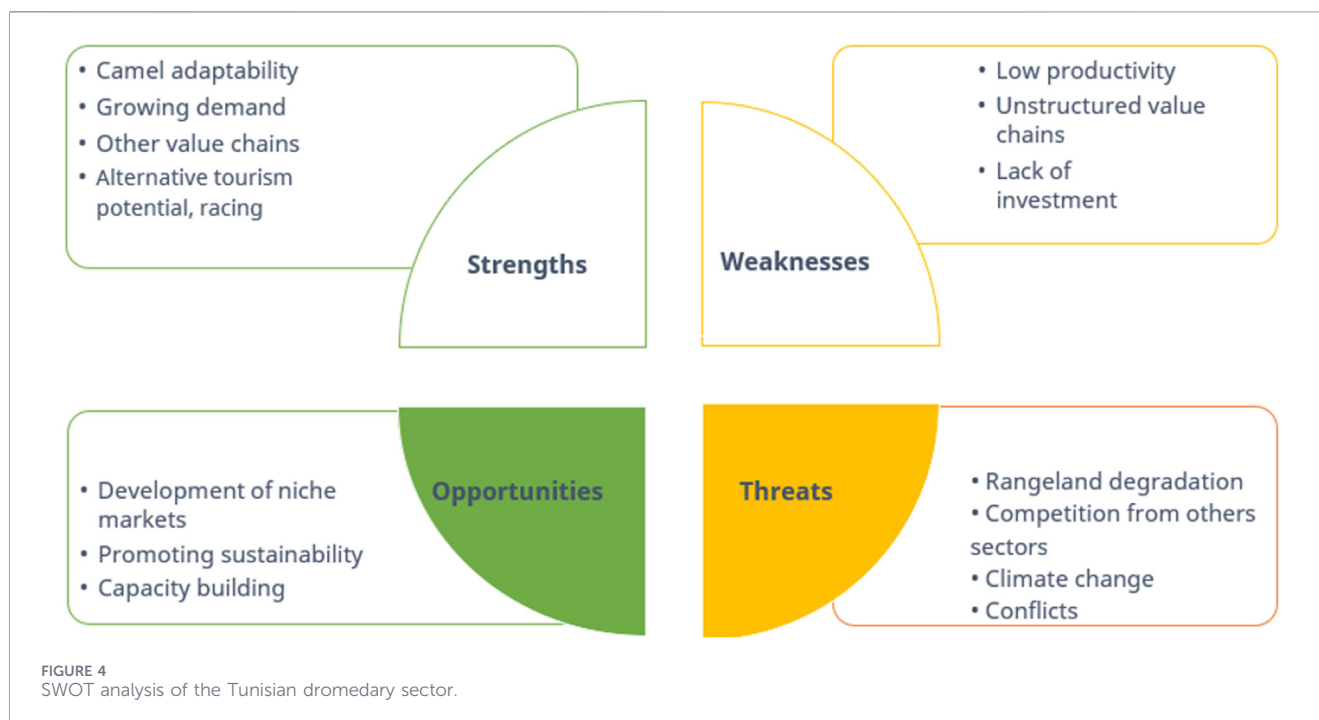
This study has several limitations that should be acknowledged when interpreting the findings. First, the KII sample size was small ($n =$

11) and comprised only three breeders, three government officials and five researchers, which constrains the diversity of perspectives and does not allow statistically generalisable conclusions about the entire Tunisian dromedary value chain. The results should therefore be read as an exploratory, qualitative diagnosis focused on information-rich informants rather than a representative survey. Second, key private sector actors such as dairy processors, urban retailers and traders from major production regions (e.g., Kebili, Tataouine, Tozeur, Medenine) were not directly interviewed, even though previous work has shown their importance in structuring camel meat and milk flows and shaping power relations in the value chain. As with all qualitative key informant interviews, our findings are shaped by respondents' subjective perceptions and may reflect recall or desirability biases; to mitigate this risk, we purposively selected interviewees from different segments of the value chain, used a semi-structured interview guide applied consistently across respondents, and applied a systematic coding framework and triangulation with existing literature to distinguish recurrent patterns from isolated views. Future research should expand the sample to include a larger and more diversified set of stakeholders and could combine KIIs with quantitative surveys to test and refine the patterns identified in this exploratory study. It is also necessary to quantify the economic viability of specific management interventions before any large-scale adoption, as this study does not provide quantitative estimates of the economic and environmental effects discussed, which limits assessment of their magnitude.

Charting the future: a SWOT-informed strategy for sustainable dromedary value chains development in Tunisia

The SWOT analysis was derived from an inductive thematic analysis of the 11 key informant interviews and the open-ended responses collected through the questionnaire. The interview notes and written responses were carefully reviewed in Excel to identify recurring units of meaning, which were then coded into initial descriptive codes by the authors. These codes were subsequently grouped into broader themes through repeated comparison across respondents. The resulting themes were then allocated to the SWOT matrix according to their substantive meaning. Themes referring to internal characteristics of the camel value chain were classified as Strengths or Weaknesses, whereas themes referring to the external environment were classified as Opportunities or Threats. To improve analytical transparency, the recurrence of the main themes was also assessed by counting the number of respondents mentioning each theme, and the most frequently reported themes are reflected in Figure 4.

According to our interviewees, the future of Tunisian dromedary value chains depends on all stakeholders' recognition of its resilience, profitability and environmental contributions. Realizing dromedary camel value chain potential is contingent on the political commitment to a holistic approach to agriculture in southern Tunisia. Otherwise, the sector may be relegated to marginalization and evolve into a luxury pursuit rather than an economically viable activity. Investment in dromedary breeding to address impacts from climate change, is likely to be necessary. A coherent development strategy will be imperative to ensure sustainable value chain viability.



Strengths

The adaptation of camels to the arid climate of Tunisia provides this species with a competitive advantage in the face of climate change. Substantial market potential is associated with domestic and global consumer demand for camel milk and camel meat products. The cultural significance of camel husbandry represents an opportunity to develop the tourism sector, and ensure a supportive policy environment. In turn, well resourced development assistance programmes provide an enabling situation for developing the camel sector. Existing and future research and development projects will be key in providing innovative and research-based knowledge for development.

Weaknesses

Low animal productivity limits the viability of enterprises and has negative consequences for market potential and competitive processing. Unstructured value chains, which consist of informal marketing channels with little processing, limit market access. Limited investment in infrastructure and weak farmer organizations limit their ability to bargain collectively, which drives a poor pricing system. Lower skill labour and limited awareness of sustainable practices severely impact the potential for driving sector sustainability.

Opportunities

Developing niche consumer markets for innovative products, such as camel milk cosmetics, will help support the growing demand for camel goods. Value chain improvement is possible by developing a more formal market structure that is linked to increasing product standardization. Demonstrating sustainable practices and training

will support their productivity and profitability. The development of public and private sector investment can further drive sector growth.

Threats

Climate change and environmental degradation represent significant threats to camel farming and rangeland ecosystems. Competition from other livestock sectors, conflicts over pastoral land between camel breeders, a lack of consumer awareness and market price fluctuations restrict market expansion. Disease outbreaks and a lack of youth involvement threaten the sector's long-term viability. Stakeholders also highlighted increasing aridity, recurrent drought and rangeland degradation as major threats to feed availability and water resources, which heighten production costs and vulnerability for camel breeders. At the same time, they emphasised that camels' physiological adaptation to heat and water scarcity gives the species a comparative advantage over other livestock under projected hotter and drier conditions, reinforcing its strategic role in southern Tunisia's changing climate.

Conclusion and recommendations

The designation of 2024 as the International Year of Camelids by the United Nations presented a valuable opportunity to enhance support for the dromedary sector in Tunisia. Realizing the full potential of this sector requires a comprehensive and multifaceted strategy centered on three main priorities: improving value chain organization, strengthening sector governance, and promoting sustainable resource management. In the short term, priority should be given to formalizing marketing channels, establishing milk collection circuits and service centers, and implementing certification and standardization of camel products. These measures would help

stabilize both prices and production volumes, and facilitate access to higher-tier domestic and international markets. Alongside these efforts, targeted consumer awareness campaigns should be developed to promote the nutritional and functional benefits of camel milk and meat, and support should be directed toward value-added processing initiatives. In the medium to long term, efforts should focus on capacity building, inclusivity, and governance reform. Producer cooperatives should be strengthened through comprehensive training programs that emphasize needs-based herd management, support services, and collective bargaining. Such efforts will improve access to resources and enhance market leverage for breeders. Additionally, improving the livelihoods of breeders by ensuring stable income opportunities and attracting youth to the sector should be prioritized. This can be facilitated through better access to government support such as subsidies, credit schemes, and employment retention initiatives. As outlined above, productive roles can also be played by public-private partnerships alongside coordinated and effective governance. To rebalance governance between central institutions and actors on the ground, strengthening and formalizing co-management arrangements between public agencies and local organizations (such as GDAs and pastoral associations), with clearly shared responsibilities for setting grazing rules and planning restoration activities is important. This should be supported by the effective implementation of the new pastoral code and decentralization policies, including the delegation of specific management mandates and budgets to local bodies, and by the creation of territorial multi-stakeholder platforms that bring together administrations, breeders, private operators and civil society to coordinate interventions and ensure that local priorities and knowledge are reflected in decision-making.

Sustainable resource management and innovation must also underpin the sector's development. Promoting genetic selection, improved technical herd management and productivity-enhancing practices should be balanced with environmental sustainability considerations. To ensure that the transition to semi-intensive systems remains compatible with low environmental impact, these systems should be conceived as complementary to, rather than a replacement for, extensive use of rangelands, with animals partially decoupled from the most fragile areas through controlled supplemental feeding based on agri-food by-products and with stocking rates and grazing periods constrained by locally defined carrying capacity and grazing rules. Public support for investment in semi-intensive units should therefore be conditional on simple environmental safeguards, including pasture-use plans and basic monitoring of vegetation and animal health, so as to avoid spillover pressure and further rangeland degradation. Implementing pasture rehabilitation programs, participatory land-use planning, and the use of agri-food by-products for feed can help combat environmental degradation while enhancing ecosystem services. Finally, developing and maintaining monitoring systems that track animal health and environmental impacts will enable adaptive management, allowing timely responses to emerging challenges and ensuring the long-term resilience of the sector and its rangeland resource base. By integrating these interconnected strategies (transforming the value chain, building capacity and inclusivity, and advancing sustainable resource management), the Tunisian dromedary sector can transition toward a more sustainable, profitable, and resilient future. Such

progress will contribute substantially to socioeconomic development, improve rural livelihoods, and promote environmental conservation across Tunisia's arid regions.

The limitations of this study include its reliance on expert perspectives, which may introduce bias, and the small sample which necessitates purposive sampling. Our method targeted diversity in the selected interview respondents, which was achieved at the expense of canvassing all product value chains in detail. We call for further research which addresses both the enterprises and value chain operational aspects of dromedary management in the rangelands, and the policy and institutional environments represented by studies over longer time frames.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

AS and BD conducted the interviews and AS, BD and DB wrote the manuscript. All authors contributed to the article and approved the submitted version.

Funding

The author(s) declared that financial support was received for this work and/or its publication. The time of the authors was supported by the project Sustainable Investments for Large Scale Rangeland Restoration (<https://www.ilri.org/knowledge/publications/stelarr-sustainable-investments-large-scale-rangeland-restoration>) funded by the Global Environment Facility (<https://www.thegef.org/>) and the CGIAR Science Program on Multifunctional Landscapes (<https://www.cgiar.org/cgiar-research-portfolio-2025-2030/multifunctional-landscapes/>) funded through the CGIAR Trust Fund (<https://www.cgiar.org/funders/trust-fund/>).

Conflict of interest

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

Generative AI statement

The author(s) declared that generative AI was not used in the creation of this manuscript.

Any alternative text (alt text) provided alongside figures in this article has been generated by Frontiers with the support of artificial intelligence and reasonable efforts have been made to ensure accuracy, including review by the authors wherever possible. If you identify any issues, please contact us.

References

- Ait El Alia, O., Zine-Eddine, Y., Kzaiber, F., Oussama, A., and Boutoia, K. (2023). Towards the improvement of camel milk consumption in Morocco. *Small Ruminant Res.* 219, 106888. doi: 10.1016/j.smallrumres.2022.106888
- Ait El Alia, O., Orche, A. E., Kaddouri, M., Boukrouh, S., Mrabet, A. E., Bouhrim, M., et al. (2024). Rapid detection of adulteration in powdered camel milk using ATR-IR spectroscopy and chemometrics. *Italian J. Food Science/Rivista Italiana di Scienza degli Alimenti* 38 (1), 1. doi: 10.15586/ijfs.v38i1.3188
- Ait El Alia, O., Chaji, S., Hajri, Z., Zine-Eddine, Y., El Orche, A., and Boutoia, K. (2025). Omics approaches for the authentication of camel milk. *Int. Dairy J.* 161, 106131. doi: 10.1016/j.dairyj.2024.106131
- Alary, V., Amsidder, L., Araba, A., Capote, C. B., Bedhiaf-Romdhani, S., Bensalem, W., et al. (2021). Social network analysis of the stakeholders involved in the dromedary sector in the mediterranean region. *Sustainability* 13 (21), 12127. doi: 10.3390/su132112127
- Amsidder, L., Alary, V., Duteurtre, G., and Mnaouer, I. (2024). The economic contribution of camel-based livestock systems in North-African drylands: the case of East and South Moroccan provinces. *Pastor. Res. Policy Pract.* 14, 13600. doi: 10.3389/past.2024.13600
- Ashton, L., and Bradshaw, B. (2023). Enabling conditions for scaling natural climate solutions in Canada's agriculture sector. *Nature-Based Solutions* 3, 100071. doi: 10.1016/j.nbsj.2023.100071
- Atigui, M., Fguiri, I., Arroum, S., Brahmi, M., Ghzaïel, B., and Hammadi, M. (2023). Effect of milking routines and hygiene practices and evolution along the market value chain on raw camel milk quality in Tunisia. *Italian J. Animal Sci.* 22, 337–346. doi: 10.1080/1828051X.2023.2188883
- Ayadi, M., Hammadi, M., Khorchani, T., Barmat, A., Atigui, M., and Caja, G. (2009). Effects of milking interval and cisternal udder evaluation in Tunisian Maghrebi dairy dromedaries (*Camelus dromedarius* L.). *J. Dairy Sci.* 92 (4), 1452–1459. doi: 10.3168/jds.2008-1447
- Bekele, B., Oneta, A., Kumbe, A., and Husein, B. (2021). Indigenous knowledge on camel milk and camel milk products hygienic handling, processing and utilization in Borana Area, Southern Ethiopia. *J. Food Sci. Nutr. Ther.* 7 (1), 025–032. doi: 10.17352/jfsnt.000029
- Bonye, S. Z., Yiridomoh, G. Y., and Nsiah, V. (2023). Our forest, our livelihood: natural resources' use controversies and community livelihood sustainability in the mole National Park, Ghana. *Land Use Policy* 127, 106589. doi: 10.1016/j.landusepol.2023.106589
- Boukrouh, S., Ait El Alia, O., and Faye, B. (2025). Worldwide camel meat and products: an extensive analysis of production, consumption patterns, market evolution, and supply chain effectiveness. *Meat Sci.* 228, 109882. doi: 10.1016/j.meatsci.2025.109882
- Chamekh, L., Khorchani, T., Dbara, M., Hammadi, M., and Yahyaoui, M. H. (2020). Factors affecting milk yield and composition of Tunisian camels (*Camelus dromedarius*) over complete lactation. *Trop. Anim. Health Prod.* 52 (6), 3187–3194. doi: 10.1007/s11250-020-02344-0
- Cheikh Ismail, L., Osaili, T. M., Mohamad, M. N., Zakaria, H., Ali, A., Tarek, A., et al. (2022). Camel milk consumption patterns and perceptions in the UAE: a cross-sectional study. *J. Nutr. Sci.* 11 (11), e59–e59. doi: 10.1017/jns.2022.55
- Christian, M., Obi, A., Zantsi, S., Mdo, L., and Jiba, P. (2024). The role of cooperatives in improving smallholder participation in agri-food value chains: a case study of one local municipality in Eastern Cape, South Africa. *Sustainability* 16, 2241. doi: 10.3390/su16062241
- Chu, C., Wang, H., Luo, X., Wen, P., Nan, L., Du, C., et al. (2023). Possible alternatives: identifying and quantifying adulteration in Buffalo, goat, and camel milk using mid-infrared spectroscopy combined with modern statistical machine learning methods. *Foods Basel, Switz.* 12 (20), 3856. doi: 10.3390/foods12203856
- Djenane, D., and Aider, M. (2024). The one-humped camel: the animal of future, potential alternative red meat, technological suitability and future perspectives. *F1000Research* 11, 1085. doi: 10.12688/f1000research.125246.2
- Eckstein, S., Ehmann, R., Gritli, A., Yahia, B., Diehl, M., Wölfel, R., et al. (2021). Prevalence of Middle East respiratory syndrome coronavirus in dromedary camels, Tunisia. *Emerg. Infect. Dis.* 27, 1964–1968. doi: 10.3201/eid2707.204873
- El Alia, O. A., Zine-Eddine, Y., Chaji, S., Boukrouh, S., Boutoia, K., and Faye, B. (2025). Global camel milk industry: a comprehensive overview of production, consumption trends, market evolution and value chain efficiency. *Small Ruminant Res.* 243, 107441. doi: 10.1016/j.smallrumres.2025.107441
- El-Seretty, S. M. A. (2014). Possibilities for developing of camels in the Most severe arid areas in the Arab world by using modern biotechnology. *American-Eurasian J. Agric. & Environ. Sci.* 14 (12), 1322–1338. Available online at: [http://www.idosi.org/aejaes/jaes14\(12\)14/1.pdf](http://www.idosi.org/aejaes/jaes14(12)14/1.pdf) (Accessed March 10, 2025).
- FAO (2024). "FAO global conference on sustainable livestock transformation – 25-27 September 2023," in *FAO Animal Production and Health Proceedings*. Editors Ruane, J., and Lucio Restrepo, M. (Rome: FAO). doi: 10.4060/cd1274en
- FAOSTAT (2024). Available online at: <http://www.fao.org/faostat/en/#data/QA> (Accessed March 10, 2025).
- Faraz, A., Younas, M., Pastrana, C. I., Waheed, A., Tauqir, N. A., and Nabeel, M. S. (2021). Socio-economic constraints on camel production in Pakistan's extensive pastoral farming. *Pastoralism* 11, 1–9. doi: 10.1186/s13570-020-00183-0
- Faye, B. (2013). Camel farming sustainability: the challenges of the camel farming system in the XXth century. *J. Sustain. Dev.* 6 (12), 2013. doi: 10.5539/jsd.v6n12p74
- Faye, B. (2020). How many large camelids in the world? A synthetic analysis of the world camel demographic changes. *Pastoralism* 10, 25. doi: 10.1186/s13570-020-00176-z
- Faye, B., Jaouad, M., Bhrawi, K., Senoussi, A., and Bengoumi, M. (2014). Elevage camelin en Afrique du Nord: état des lieux et perspectives. *Revue d'élevage de médecine vétérinaire des pays tropicaux* 67 (4), 213–221. doi: 10.19182/remvt.20563
- Faye, B., Konuspayeva, G., Nari, A., Koç, A., and Medina-Diaz, E. (2025). The camel milk sector in Mediterranean Basin. *J. Camel Pract. Res.* 32, 1–8. doi: 10.5958/2277-8934.2025.00001.8
- Frija, A., Carpentier, I., Sghaier, M., Sghaier, M., Rudiger, U., Idoudi, Z., et al. (2024). "Concept and perspectives for a pastoral living landscape (PLL) on livestock and climate innovations in south Tunisia," in *International Center for Agricultural Research in the Dry Areas (ICARDA). Internal Report*, 14. Available online at: <https://hdl.handle.net/20.500.11766/69672> (Accessed April 24, 2025).
- Gamoun, M., Belgacem, A. O., and Louhaichi, M. (2018). Diversity of desert rangelands of Tunisia. *Plant Diversity* 40 (5), 217–225. doi: 10.1016/j.pld.2018.06.004
- Harek, D., El Mokhefi, M., Ikhlaf, H., Bouhadad, R., Sahel, H., Djellout, N., et al. (2022). Gene-driving management practices in the dromedary husbandry systems under arid climatic conditions in Algeria. *Pastoralism* 12 (1), 1–12. doi: 10.1186/s13570-021-00219-z
- Helms, M. M., and Nixon, J. (2010). Exploring SWOT analysis-where Are we now? *J. Strategy Manag.* 3, 215–251. doi: 10.1108/17554251011064837
- Hidayati, D. R., Garnevska, E., and Childerhouse, P. (2021). Sustainable agrifood value chain transformation in developing countries. *Sustainability* 13 (22), 12358. doi: 10.3390/SU132212358
- Jaouad, M. (2016). "Etude de la filiere cameline dans le gouvernorat de Medenine," in *Rapport de Diagnostic Général* (IRA, Medenine-Tunisia: Institut des Régions Arides de Médénine), 133.
- Jemli, M. H., Boulajfene, H., Azouzi, Z., Salem, W. B., and Khaldi, S. (2018). Camel breeding development project in Tunisia. *Rev. Maroc. Sci. Agron. Vét* 6, 256–259.
- Kamili, A., Faye, B., Tligui, N., and Bengoumi, M. (2020). Typologie des systèmes d'élevage camélins du sud du Maroc. *Revue d'élevage de Médecine Vétérinaire des Pays Tropicaux* 73 (2), 71–80. doi: 10.19182/REMT.31862
- Khaldi, Z., Nafti, M., and Jilani, M. T. (2022). Baseline composition and microbial quality assessment of raw milk from small ruminants and Maghrebi camels in the oasis area of Tunisia. *Trop. Anim. Health Prod.* 54 (6), 391. doi: 10.1007/s11250-022-03408-z
- Laâbar, M., Sghaier, M., and Jaouad, M. (2024). Polycentric governance of collective rangelands in southern Tunisia: paving the way for coordination. *Afr. J. Land Policy Geospatial Sci.* 7 (3), 827–846. doi: 10.48346/IMIST.PRSM/ajlp-gs.v7i3.47542
- Lelenguyah, G., Nyangito, M., Wasonga, O., and Bett, R. (2021). Perception of key informants on climate variability, livestock diseases, herd mobility and the adaptation strategies of local pastoralists in Samburu County, Kenya. *Int. J. Trend Sci. Res. Dev. (IJTSRD)* 6 (1), 274–279. Available online at: www.ijtsrd.com/papers/ijtsrd47777.pdf.
- Letaief, S., and Bedhiaf-Romdhani, S. (2022). "Camel herd management under pastoral system in southern of Tunisia," in *Addressing the Challenges of agro-pastoral Farming Systems to Strengthen Their Resilience (Options Méditerranéennes :Série A. Séminaires Méditerranéens; n. 129)*. Editors G. Hadjipavlou and C. Ligda (Zaragoza: CIHEAM, 2022), 57–62.
- Liniger, H. P., Hauert, R. M. S. C., and Gurtner, M. (2011). *Sustainable Land Management in Practice – Guidelines and Best Practices for Sub-Saharan Africa. TerrAfrica, World Overview of Conservation Approaches and Technologies (WOCAT) and Food and Agriculture Organization of the United Nations (FAO)*.
- Machan, S. N., Agwata, J. F., and Ouge, N. O. (2022a). Environmental factors influencing the sustenance of the camel milk value chain in Isiolo County, Northern Kenya. *Resources* 11 (3), 27. doi: 10.3390/resources11030027
- Machan, S. N., Agwata, J. F., and Ouge, N. O. (2022b). Aspects of the sustainability of the camel milk value chain and its regulatory framework in Isiolo County, Northern Kenya. *J. Agric. Food Syst. Community Dev.* 11 (2), 199–216. doi: 10.5304/jafscd.2022.112.007
- Marshall, M. N. (1996). The key informant technique. *Fam. Practice* 13, 92–97. doi: 10.1093/fampra/13.1.92
- Mekuria, W., Tadesse, M., Admassu, W., Asmame, B., Tessema, A., Abebe, S., et al. (2023). The role of landscape management practices to address natural resource degradation and human vulnerability in Awash River basin, Ethiopia. *Curr. Res. Environ. Sustain.* 6, 100237. doi: 10.1016/j.crsust.2023.100237
- Morizet-Davis, J., Marting Vidaurre, N. A., Reinmuth, E., Rezaei-Chiyaneh, E., Schlecht, V., Schmidt, S., et al. (2023). Ecosystem services at the farm level—Overview, synergies, trade-offs, and stakeholder analysis. *Glob. Challenges* 7 (7), 2200225. doi: 10.1002/gch2.202200225

- Muthukumaran, M., Mudgil, P., Baba, W., Ayoub, M., and Maqsood, S. (2022). A comprehensive review on health benefits, nutritional composition and processed products of camel milk. *Food Rev. Int.* 39, 3080–3116. doi: 10.1080/87559129.2021.2008953
- Nagy, P. (2016). Camel milk from commodity to added value product. The science behind the development of the camel dairy industry. *J. Animal Sci.* 94 (94), 442. doi: 10.2527/jam2016-0918
- Nagy, P., Skidmore, J. A., and Juhasz, J. (2022). Intensification of camel farming and milk production with special emphasis on animal health, welfare and the biotechnology of reproduction. *Animal Front. Rev. Mag. Animal Agric.* 12 (12), 35–45. doi: 10.1093/af/vfac043
- Naji, R., and Kandeel, M. (2024). A bibliometric analysis of six decades of camel research in North Africa: trends, collaboration and emerging themes. *Open Veterinary J.* 14 (12), 3505. doi: 10.5455/ovj.2024.v14.i12.34
- Najjar, A., El Mahroug, H., Hechlef, H., and Khaldi, S. (2024). Diagnosis of actors and relational flows of camel meat value chain in the Western south of Tunisia. *Int. J. Innovative Approaches Agric. Res.* 8 (1), 1–14. doi: 10.29329/ijiaar.2024.656.1
- Nielsen, U. N., Stafford-Smith, M., Metternicht, G. I., Ash, A., Baumber, A., Boer, M. M., et al. (2020). Challenges, solutions and research priorities for sustainable rangelands. *Rangel. J.* 42 (5), 359–373. doi: 10.1071/RJ20059
- Nouairia, G., Kdidi, S., Salah, R. B., Hammadi, M., Khorchani, T., and Yahyaoui, M. H. (2015). Assessing genetic diversity of three Tunisian dromedary camel (*Camelus dromedarius*) subpopulations using microsatellite markers. *Emir. J. Food Agric.* 27 (4), 362–366. doi: 10.9755/ejfa.v27i4.19258
- Ouled, B. A., and Louhaichi, M. (2017). Rangeland restoration and management in relation to land tenure and vegetation type: the revival of the resting “Gdel” technique in southern Tunisia. Jordan: International center for agricultural research in the dry areas (ICARDA). *Tech. Rep.* 20. Available online at: <https://hdl.handle.net/20.500.11766/8276> (Accessed June 11, 2025).
- Ouled Belgacem, A., Ben Salem, F., Gamoun, M., Chibani, R., and Louhaichi, M. (2019). Revival of traditional best practices for rangeland restoration under climate change in the dry areas: a case study from Southern Tunisia. *Int. J. Clim. Change Strategies Manag.* 11 (5), 643–659. doi: 10.1108/IJCCSM-02-2018-0019
- Qureshi, F. (2024). Sustainable resource management: balancing human needs and environmental protection. *Front. Environ. Sci. Sustain.* 1 (1), 1–19. doi: 10.71465/fess98
- Rjili, H., Muñoz-Ulecia, E., Bernués, A., Jaouad, M., and Martín-Collado, D. (2023). Evolution of pastoral livestock farming on arid rangelands in the last 15 years. *Animal An International Journal Animal Bioscience* 17 (4), 100748. doi: 10.1016/j.animal.2023.100748
- Salmi, C., Jaouad, M., and Faye, B. (2024). Valorisation marchande du lait de chamelle en Tunisie: comment faire? *Rev. Des Régions Arid.* (49), 333–342.
- Sanz, M. J., de Vente, J. L., Chotte, M., Bernoux, G., Kust, I., and Ruiz, M. (2017). “Sustainable land management contribution to successful land-based climate change adaptation and mitigation,” in *A Report of the Science-Policy Interface, 178p. Published in 2017 by United Nations Convention to Combat Desertification (UNCCD)* (Bonn, Germany).
- Selmi, C., Jaouad, M., Faye, B., and Rjili, H. (2017). Situation of the camel meat sector in southeastern Tunisia: case of the governorate of Medenine. *J. New Sciences, Agric. Biotechnol.* CSIEA (7), 2648–2653.
- Selmi, C., Jaouad, M., Faye, B., and Haouat, F. (2018). “Typologie des éleveurs camelin au sud-est tunisien en vue de leurs performances économiques. *Revue des Régions Arides* (44), n° spéc,” in *Colloque International Développement socio-économique et Dynamique Des Sociétés Rurales: Pluralité D’Acteurs, Gestion Des Ressources Et Développement Territorial, Zarzis, Tunisie, 3 Mai 2016/5 Mai 2016*, 209–214.
- Sharafatmandrad, M., and Khosravi Mashizi, A. (2021). Linking ecosystem services to social well-being: An approach to assess land degradation. *Front. Ecol. Evol.* 9, 654560. doi: 10.3389/fevo.2021.654560
- Singh, R., Maiti, S., and Garai, S. (2023). Sustainable intensification – reaching towards climate resilience livestock production system. *Ann. Animal Sci.* 23 (4), 1037–1047. doi: 10.2478/aoas-2023-0027
- Tardif, N., Jaouad, M., Khorchani, T., and Faye, B. (2014). Contribution of camel breeding to the household economy in southeast Tunisia. *Options Méditerranéennes* 109.
- Teno, G. (2022). *Sustainable Livestock Value Chains for Rangeland Restoration in Four Countries of the Great Green Wall: Challenges and Opportunities for Commercial Sector Investors*. Nairobi, Kenya: ILRI.
- Thabet, C. (2024). Improving agricultural policies to enhance food security in Tunisia: a retrospective and prospective analysis. *New Medit Mediterr. J. Econ. Agric. Environ.* 23 (3). doi: 10.30682/nm2403g
- Tidjani, Y., Adamou, A., and Boudjenah, S. (2025). The marketing of camel milk in the Ouargla region: its opportunities and limits. *Asian J. Dairy Food Res.* 1–5. doi: 10.18805/ajdfr.drf-421
- Yakubu, A., Okpeku, M., Shoyombo, A. J., Onasanya, G. O., Dahloum, L., Çelik, S., et al. (2022). Exploiting morphobiometric and genomic variability of African indigenous camel populations-A review. *Front. Genet.* 13, 1021685. doi: 10.3389/fgene.2022.1021685
- Yeleliere, E., Antwi-Agyei, P., and Nyamekye, A. B. (2023). Mainstreaming Indigenous knowledge systems and practices in climate-sensitive policies for resilient agricultural systems in Ghana. *Soc. & Nat. Resour.* 36 (6), 639–659. doi: 10.1080/08941920.2023.2183446
- Zammouri, A., Fguiri, I., Ziadi, M., Arroum, S., Dbara, M., Hammadi, M., et al. (2024). Physicochemical characteristics and microbiological quality of camel milk in Tunisian arid lands: a comparison with goat and sheep milk. *J. Camel Prac. Res.* 31 (3), 325–331. doi: 10.5958/2277-8934.2024.00059.7