



REVIEW

Advancement in assisted reproductive technologies in the dromedary: Opportunities and challenges for Kenya

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Abstract

Background: Dromedaries have a central economic, social, and cultural role for pastoralist communities in Africa, particularly in arid and semi-arid regions marked by recurrent droughts and scarce vegetation. In these harsh environments, camel milk and other products are a primary source of livelihood and an important source of nutrients for the whole household. Despite their importance, the genetic potential of the dromedary in Kenya remains largely underexploited, with traditional camel-keeping practices still primarily performed. For several decades, there has been minimal investment and research in dromedaries in Kenya, with the economic and ecological significance of camels kept by pastoralist communities undervalued. The situation is changing rapidly as demand for camel products in the global market is rising and consumption is increasing due to their nutritional and health benefits. **Methods:** This review examines traditional camel management practices, current breeding strategies, the use of genomic tools, and reproductive technologies for dromedaries in Kenya. The technological advances in dromedary breeding in the Middle East (Saudi Arabia and the United Arab Emirates) are evaluated, and their successes, challenges, and applications to the Kenyan scenario are discussed. A thorough data-mining exercise was conducted to document publications on the use of technologies such as artificial insemination, embryo transfer, cloning, and marker-assisted selection in the dromedary in Kenya and globally. **Results:** No studies documented the use of any Assisted Reproductive Techniques (ARTs) in dromedaries in Kenya. On the African continent, the use of reproductive technologies was reported in North Africa mainly Egypt. Our findings indicated that management and breeding practices in Kenyan camels are primarily based on applying indigenous knowledge to select breeding stock based on parental historical performance, adaptability, milk yield, and disease resistance. We have explored the challenges of implementing breeding technologies in pastoralist systems, such as a lack of a cold chain for semen conservation, poor infrastructure, limited funding and investment in the camel sector, and socio-cultural beliefs that may hinder technology adoption. **Conclusion:** We recommend strategies to overcome the barriers, such as systematic genetic evaluation, structured selection of superior breeding females and bulls, and community-based breeding programs as practical, sustainable pathways for genetic improvement and optimal utilization of camel genetic resources in extensive production systems.

Keywords: dromedary camel, Kenya, pastoralist, extensive systems, camel milk, camel meat

Introduction

Dromedaries are an integral source of livelihood for rural pastoralist communities across Africa. For decades, camel farming has primarily been practiced in the continent's arid and semi-arid regions, where harsh climatic conditions have supported pastoral and nomadic lifestyles. Dromedaries in Kenya make up 10 and 12% of the world's and Africa's camel population, respectively. They are mainly found in arid and very arid areas that receive the

least annual rainfall, typically less than 400 mm, characterized by prolonged droughts and have low agricultural land use. Due to the poor availability of feed resources for livestock, extensive and nomadic pastoralism is the main economic activity, and livestock are the primary livelihood source (Guliye *et al.*, 2007).

The camel's unique adaptation to drought conditions has historically supported multiple roles, from its designation as the "ship of the desert" used for transportation across arid lands to its contribution

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to subsistence farming (Faye, 2016; Amsidder *et al.*, 2024). Even today, the survival of many pastoralist communities within the desert lands remains closely tied to camels (Guliye *et al.*, 2007; Faye, 2013; Asimwe *et al.*, 2020). Camel milk and meat are the two most important products consumed by the pastoralist communities. The dromedary can maintain their milk production even during prolonged droughts when pastures and water supply are scarce, a situation which would result in other livestock species' milk production being adversely affected. Due to this unique characteristic in an environment where the effects of climate change are evident, pastoralist communities in Kenya are shifting their herd composition from cattle to camels (Kagunyu and Wanjohi, 2014). Milk is a daily dietary intake food for the camel herders in Kenya, for example, during prolonged drought seasons in Northern Kenya, camel milk makes up to 50% of the nutrient uptake in pastoralist communities when other livestock can no longer sustain milk production (Oselu *et al.*, 2022).

Camel meat is an enriched source of high-quality protein. Camels are a good source of meat as they yield reasonably heavy carcasses under inexpensive management systems (Kadim *et al.*, 2008). The high protein and other nutrient content of camel meat provide a valuable complement to low-protein diets, particularly for vulnerable groups such as children and pregnant women.

In addition to human nutrition and food security, camels also play a crucial role in religious and social activities within the communities in Kenya. They are a symbol of wealth and social status in the society; among the livestock kept by pastoralists, camels are most valued and highly priced. Additionally, they are used to pay dowry, as gifts, or to compensate the injured party in tribal clashes (Guliye *et al.*, 2007). Despite this importance, the economic value of the dromedary has long been underestimated. Nonetheless, the camel sector has gained increasing recognition in recent years, driven mainly by growing global demand for camel milk and meat (Faye, 2013) and the expanding camel milk market in Kenya (Nori, 2023).

During the last few decades, Kenya's camel population has increased and spread among non-traditional camel-keeping communities, as pastoralists had to adapt to an increasingly arid environment and recurring drought (Kagunyu and Wanjohi, 2014). Kenya reported a camel population of 4.28 million in 2023, a significant growth (47.8%) from 2.89 million heads of camels in 2013 (Fig. 1). Despite this overall upward trend, the camel population in Kenya has fluctuated over the last 5 years, with some years reporting severe decline. For instance, between 2019 and 2022, Kenya recorded a 10% reduction in camel numbers, with the sharpest drop occurring

in 2022, when the population decreased by 1.27 million compared to 2021. This decline coincided with a severe drought in northern Kenya, which resulted in the loss of an estimated 2.5 million livestock (DRC, 2022; UN-OCHA, 2022). Following this crisis, the return of rainfall, improved forage availability, and restocking initiatives by non-governmental organizations contributed to a rapid rebound of camel herds, with numbers increasing by 23.93% (FAOSTAT, 2023). This recovery highlights both the resilience of the camel sector and the adaptive capacity of pastoralist communities in the face of climatic shocks.

The observed increase in Kenya's camel population can be partly attributed to climate change, particularly global warming. Due to their exceptional adaptability to drought and heat, camels have become the preferred livestock under these conditions (Nori, 2023). This growth is also linked to changing human dietary preferences, growing acceptance of camel products, resulting in an increase in the inclusion of camel products in food practices (Volpato and King, 2019). Additionally, the export of live camels from East Africa to Middle East countries is a rapidly expanding market (Aklilu and Catley, 2011; Faye, 2018; IGAD, 2023). Collectively, these trends suggest that the dromedary in Kenya is gradually shifting from its traditional role as a subsistence animal to a commercial enterprise aligned with global trade demands. The commercialization of camel products has, in turn, stimulated research across various domains, including milk and meat production, beauty and racing traits, and disease diagnosis and management worldwide.

Camel milk production in Kenya has been on the rise of the last 10 years with a record of 0.870 million tons in 2013 to 1.026 million tons in 2023 (Fig. 2). The rise in milk volumes produced, follows the increase in population with drops in camel populations in the year 2022 also reflected in significant drop in milk volume reported (Figs. 1 and 2). Notably, the amount of milk produced is directly related to the camel population. For instance, milk production declined between 2019 and 2021, with a sharp 18% drop in 2022, a year marked by severe drought that led to mass livestock losses. A rapid rebound followed as the camel herds were rebuilt, as reflected in increased camel numbers and, consequently, milk production. These patterns highlight the significant dependence of milk production on camel population, particularly the number of lactating females. They also reveal the limited role of human interventions in enhancing production and welfare traits through reproductive technologies, nutritional supplementation, or genomic selection. This raises an important question: could the introduction of targeted interventions increase milk yields while simultaneously reducing reliance on herd size expansion?

KENYA CAMEL POPULATION TRENDS

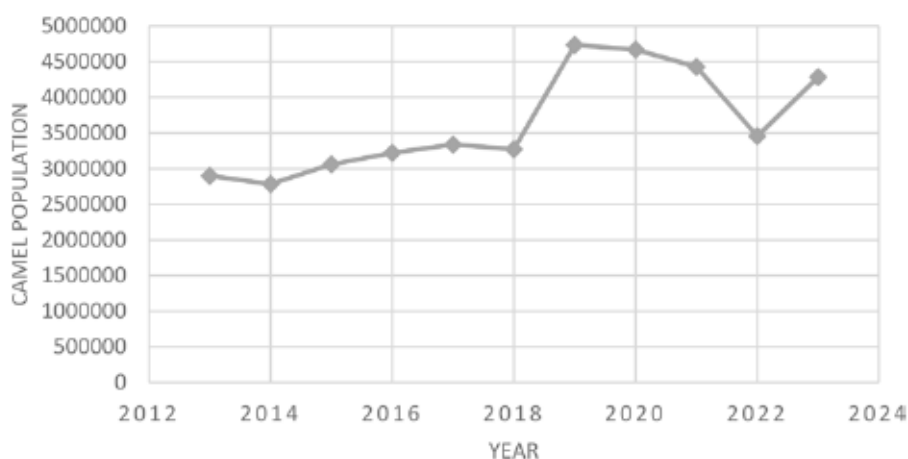


Fig. 1. Kenya's camel population trends over the last 10 years. Data source: FAOSTAT (2023).

A comparison of the dromedary camel population and milk production between Kenya and its neighbors in East Africa and the Middle East was conducted to examine differences in the dromedary production system (Tables 1 and 2). The Middle East is documented to have intensive to semi-intensive production systems, while East Africa has purely extensive systems, with the development of a few commercial dairy camel farms near camel milk markets. Furthermore, research on camel ARTs has primarily been conducted in the Middle East, namely the United Arab Emirates (UAE), Saudi Arabia, and Qatar, with a few reports in Oman and North African countries, including Egypt.

The number of dromedary populations is reportedly high in East Africa, with pastoralists crossing borders from Kenya into neighboring countries, i.e., Somalia, Ethiopia, Djibouti, and Sudan, and vice versa in search of water and pasture. The challenges and dynamics of pastoralism are similar across these countries, and camels' contribution to pastoral livelihoods is irreplaceable. However, the vast populations of camels in Africa do not necessarily imply a direct contribution to the national economy

or livestock resources. The significance of camels in a country's livestock economy can be estimated by comparing the number of camel heads to the total number of tropical livestock units (TLU). Kenya and Sudan fall within the category of a medium proportion of camel livestock (5–15% of TLU). Countries with an extremely high proportion of camel livestock (more than 35% TLUs) include Somalia, the UAE, and Qatar, highlighting the importance of camels in the economies of these countries (Faye, 2020). The medium number of camel populations observed among pastoralists in Kenya and neighboring East Africa is not unexpected, as herd size is strongly linked to social stature, cultural practices, and the expansion of camel keeping communities (Volpato and King, 2019). However, over the past few decades, the sustainability of this production system has come under increasing strain due to demographic pressures, generational shifts, changes in land tenure, and the shrinking availability of communal grazing lands.

According to FAOSTAT global rankings, Kenya was the leading camel milk producer in 2023, recording 1.0264 million tons, followed closely by Somalia with 0.993 million tons, while Saudi Arabia

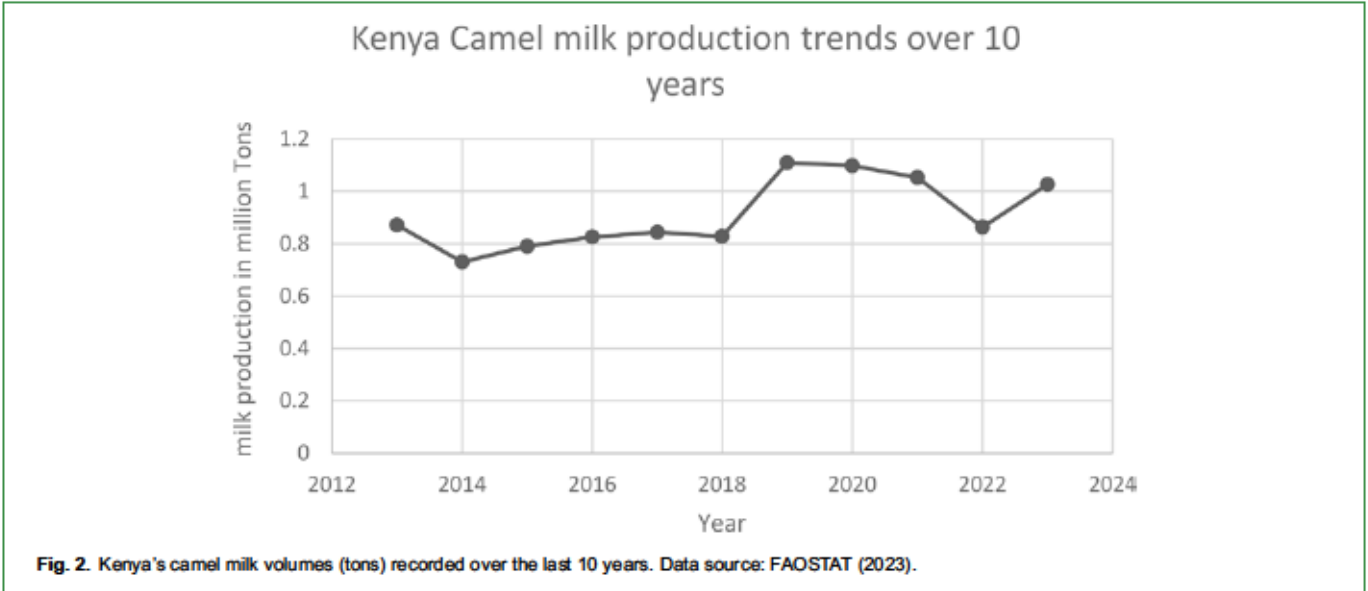


Table 1. Annual camel heads populations recorded over 10 years.

Annual camel heads per country						
	2013	2015	2017	2019	2021	2023
Kenya	2,899,244	3,059,840	3,338,757	4,735,351	4,427,881	4,284,497
Somalia	7,100,000	7,214,325	7,331,790	7,439,553	7,484,594	7,541,593
Sudan	4,773,000	4,809,000	4,850,000	4,895,000	4,826,209	4,770,095
Ethiopia	1,098,312	1,228,023	1,418,457	1,486,961	1,664,723	1,755,349
Djibouti	71,000	70,991	71,060	71,019	71,858	72,130
Egypt	152,946	152,518	155,713	91,000	239,000	193,667
Morocco	57,000	57,500	59,000	60,661	63,510	65,505
Tunisia	237,000	236,860	237,396	238,050	238,592	239,042
Qatar	68,371	84,216	105,387	131,080	119,560	100,726
Saudi Arabia	233,085	476,398	485,926	492,853	1,390,091	1,981,605
United Arab Emirates	392,667	430,372	459,971	494,536	549,458	579,600

Data source: FAOSTAT (2023).

Table 2. Camel raw milk in East Africa comparable to other countries.

Annual raw camel milk yield						
Country	2013	2015	2017	2019	2021	2023
Kenya	870,864	790377.24	843347.25	1109098.98	1052397.0	1026467.15
Somalia	1,100,000	952820.17	967516.56	980107.04	986187.97	990001.63
Sudan	60,000	61,000	61,000	62,000	61222.99	60853.16
Ethiopia	158766.51	254092.71	327,638	182,032	217365.17	226519.61
Djibouti	6613.62	6039.69	6055.82	6059.42	6114.63	6138.23
Egypt	Missing					
Morocco	8698.91	8458.47	8750	8640.12	8932.15	9138.78
Tunisia	1400	1092.43	1095.52	1100.08	1102.73	1105.2
Qatar	5345.8	14721.19	17185.34	19909.89	18676.06	16555.83
Saudi Arabia	105,000	119,950	122,250	134,150	137,070	136003.33
United Arab Emirates	33,860	54,300	80,780	74,630	97,000	89367.78

produced comparatively less at 0.136 million tons (Table 2). However, the FAOSTAT data do not account for the camel's lactation status, making it difficult to estimate the proportion of lactating animals within reported populations. A crude comparison of the 10-year milk production and camel heads (2013–2023) further illustrates disparities between the two measures. However, this is partly due to the low volumes of camel milk produced; for example, the highest camel milk producer, the Somali breed in Kenya, produces between 3 and 5 kg of milk daily, with a lactation period of between 12 and 18 months. Other camel ecotypes in Kenya, the Rendille and Gabbra, have been documented to produce between 1 and 3 kg daily in a lactation period of between 12–18 months (Oselu *et al.*, 2022). Similarly, milk production parameters in the intensive management system in the United Arab Emirates recorded a mean daily milk yield of 6.0 ± 0.12 kg, with peaks of up to 8.5 kg, and a mean lactation period of 586 ± 11.0 days (Nagy *et al.*, 2013). In Saudi Arabia, in intensive camel management system, the daily average milk yield of 4.8–6.8 kg within a lactation length period of 12.5 months was reported (Musaad *et al.*, 2013).

Since their domestication on the east coast of the Arabian Peninsula (Almathen *et al.*, 2016), dromedaries were used by the Bedouins, who had a nomadic pastoral lifestyle across the deserts of the Arabian Peninsula, for transportation, cultural practices, and food provision (Prager, 2014). Over the past decades in this region, especially in the UAE, Saudi Arabia, and Qatar, the roles of camels have changed, although deep-rooted camel socio-cultural heritage practices have been maintained. The dromedary sector has undergone tremendous technological innovations in camel breeding, racing, beauty competitions, and the commercialization of camel products (Khalaf, 2000; Bridi and De Man, 2025). The traditional pastoral system of camel management has paved the way for semi-intensive and intensive systems, with milking machines used on some farms in Middle Eastern countries.

Furthermore, reproductive biotechnologies (artificial insemination, embryo transfer and cloning) have been developed for use in the dromedary in this region, commercial widespread use among camel breeders is not documented (Faye, 2016; Bridi and De Man, 2025). Camel populations, particularly in the UAE and Saudi Arabia, have been increasing alongside the global rise in camel numbers. In the UAE, the camel population increased from 392,667 in 2013 to 579,600 in 2023, with an average annual growth rate of approximately 3.98%. According to Bridi and De Man (2025), this growth may be linked to camel being a form of identity, social

status and heritage to the camel keepers. Secondly, effective breeding strategies, reproductive technologies, genetic research, and substantial investment by the government and camel breeders might have an effect. Thirdly, the UAE's economic diversification, with increased investment in camel racing and beauty contests, has contributed to population growth. The ongoing intensification of camel management has driven increased genetic research and utilization of ARTs (artificial insemination, embryo transfer and cloning).

The ARTs are technologies developed to accelerate genetic progress by manipulating the estrus cycle, gametes (sperm and eggs), or embryos to produce offspring of high genetic value. The techniques include artificial insemination (AI), Multiple Ovulation and Embryo Transfer (MOET), In Vitro Embryo Production (IVEP), somatic nuclear transfer, and cloning (Nagy *et al.*, 2013; Wani, 2021). We will delve into the extent of these technologies' applications in the dromedary camel in this review.

Artificial insemination enables the dissemination of elite genetics worldwide by dividing a single ejaculate into 2–3 semen doses, resulting in faster genetic gains. The process of AI begins with the collection of semen from a male, processing and preservation of the semen, and lastly transferring the semen to the female reproductive tract. The development of artificial insemination in camels has faced unique challenges due to the species' reproductive physiology: camels are induced ovulators; thus, ovulation is triggered by mating or AI. Additionally, the gelatinous nature of semen causes difficulties in effective semen preservation (Skidmore *et al.*, 2013). Despite these challenges, AI has been successfully applied in camels, especially in the Middle East. This technique has been effective in enhancing traits such as racing performance, milk production, and aesthetic qualities in the camel (Skidmore *et al.*, 2020; Wani, 2021).

Embryo transfer involves the transfer of an embryo from one female into a surrogate female to carry the pregnancy to term. Embryos are produced through two processes: (i) *In vivo* embryo production, which involves superovulation of the females, AI or mating, then embryo recovery, and the transfer of the recovered embryos are then transferred to prepared surrogate females; and (ii) *In vitro* embryo production as described in more detail in the section "Use of ARTs". The interest in *in vitro* fertilization (IVF) has mainly been driven by the development of lucrative, technologically advanced camel sports and beauty contests, and by the establishment of specialized dairy camel farms that demand high milk production.

Although offspring have been produced using this technology, the efficiency and success rate are variable and low (Tinson *et al.*, 2000, 2001a; Wani, 2021).

Animal cloning via somatic cell nuclear transfer (SCNT) provides the possibility of producing live offspring without fusion of the sperm and egg. The offspring produced is nearly similar to the original animal that donated the somatic cell. This technique is expensive, has low efficiency and low offspring survival rates. A small number of offspring have been produced through camel cloning over the last 10 years (Wani *et al.*, 2010; Niasari-Naslaji, 2023).

Finally, the use of genomic tools to select breeding camels has gained momentum with advances in genetic research and identification of genetic markers associated with specific desirable traits (Burger *et al.*, 2019). Selective breeding in the camels in the Arabian Peninsula has mainly focused on propagating racing performance, camels for beauty contests, increased milk production and disease resistance (Abri and Faye, 2019; Al Abri *et al.*, 2023). There is a significant potential in the camel industry in Kenya that remains underutilized due to technical, logistical, and economic challenges. The successful integration of selective breeding through marker-assisted selection, genomic selection, and ARTs has the potential of improving the reproductive and production performance of the camel, as well as the physical performance in sports; however, more research and huge investments are needed for these to be attained (Abri and Faye, 2019).

In this review, we collate available information on camel reproductive management and the use of ARTs in dromedaries in Kenya and globally. The main questions addressed here include (i) what are the ARTs used in dromedaries in African countries, specifically Kenya, and (ii) what are the current limitations and possibilities for reproductive and other technologies in the dromedary sector in Kenya?

Methodology: Systematic literature review in dromedary ARTs

A thorough literature search was conducted to collate materials on the dromedary, its population, and advancements in breeding technology over the past 30 years, utilizing three search engines: PubMed, Google Scholar, and Elsevier. FAOSTAT® data on milk production and global camel populations were retrieved. Information was gathered from journal articles, conference papers, reports, and book chapters. For additional materials on the subject under study, news articles, organizational websites, and other sources were read. The dromedary has been referred to by different names, including “*Camelus dromedarius*”, “large camelids”, “Arabian camel”, “dromedary camel”, and “one humped camel”. During the search, all these names were factored in to ensure that all available articles were retrieved. In addition to the dromedary camel, other key search terms used included: “Assisted reproductive technologies in camels”, “embryo transfer in camels”, “Artificial Insemination”, “Cloning in camels”, “In vitro embryo production in camels”, “Genetic selection of camels”. The search was conducted between January and June 2025. The data was filtered through specific inclusion criteria to involve articles from dromedaries only and focusing on either of the reproductive technologies (Fig. 3).

All retrieved articles ($n = 1615$) were imported into Zotero (<https://www.zotero.org>), a reference manager, and then exported to Rayyan Intelligent Systematic Review software (<https://www.rayyan.com>) for screening. Duplicates were removed, and titles and abstracts were assessed for relevance. Full texts were reviewed when appropriate. A total of 663 unique articles were retained after screening, of which 99 high-quality studies – assessed according to Cochrane guidelines (<https://www.cochrane.org/handbook>) – were included in the final data extraction (Preferred Reporting Items for Systematic Reviews and Meta-Analyses: PRISMA; Fig. 3). We noted the limited use of assisted reproductive technologies

in dromedary in Africa, except North Africa, and the unavailability of published information on reproduction technologies in Kenya. Therefore, data on ARTs in the dromedary are skewed toward the Middle East, particularly the UAE and Saudi Arabia, where most published reports have been conducted.

For each study, the following data were extracted into an Excel spreadsheet: The country in which the study was done, reproductive/genetic technologies investigated (artificial insemination, superovulation, embryo transfer, in vitro fertilization, animal cloning, genomic selection), success rates, and whether technologies had been applied commercially or remained experimental. The review covered literature published up to June 2025.

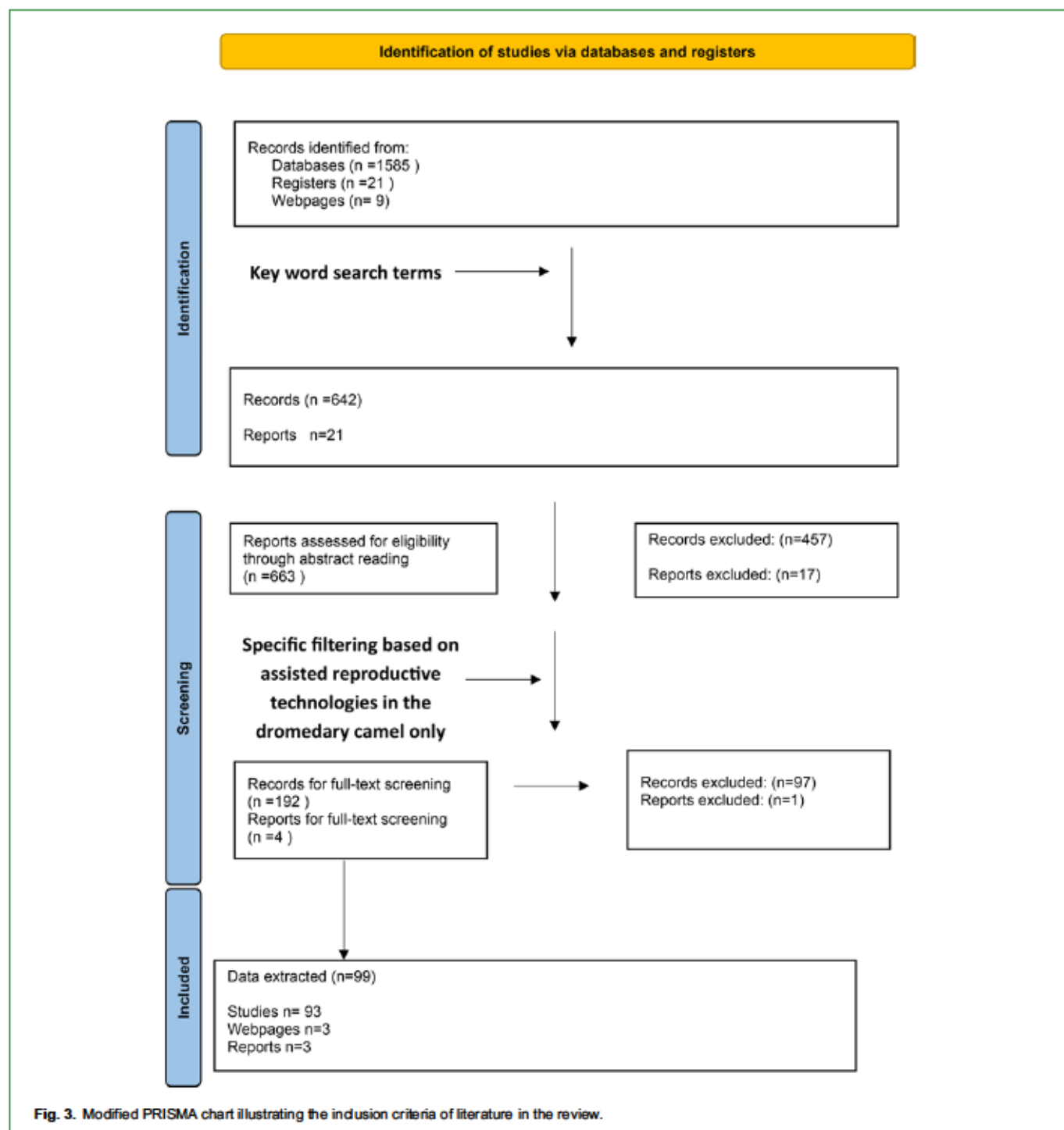
The authors are currently investigating the application of genomic tools to improve dairy camel production and to characterize the genetic diversity of Kenyan dairy dromedary camels; therefore, some preliminary findings are referenced. Based on the literature search, the status of the following topics will be outlined and elaborated: the dynamics of camel production systems ranging from extensive to semi-intensive and intensive. The management of breeding and the use of ARTs across various systems, the barriers to adopting these technologies in dromedary camel systems in Kenya, strategies to overcome these challenges, and available technological options for genetic improvement of dromedaries in Kenya will be examined.

Dynamics of dromedary production systems: Management, breeding, and use of ARTs

In this article, we will discuss the changes in the production systems and their associated drivers, the production under extensive systems and breeding practices in these systems, and lastly the utilization of ARTs. The barriers and strategies for introducing ARTs in the dromedary sector in Kenya are further explored.

INTENSIFICATION OF THE DROMEDARY PRODUCTION SYSTEMS: SHIFT FROM EXTENSIVE SYSTEMS TO SEMI-INTENSIVE AND INTENSIVE SYSTEMS

Since their domestication, dromedaries have been traditionally kept by nomadic pastoralists, but today the camel population has expanded beyond this group. Stationary pastoral systems have evolved, driven by population growth, changes in land ownership, urbanization, sedentarization, and climate change. Although the nomadic pastoralist population has decreased from 10 to 1.5% over the last five decades, the global annual growth rate of the camel population is 2.0% (Faye, 2018). As the world's nomadic pastoralist population decreases, Kenya has followed a similar pattern, with a large proportion of nomads shifting to a sedentary lifestyle. This settlement has resulted from their involvement in the camel milk market, and therefore, the camel herds remain accessible to camel milk collection points near towns. Other contributing factors to the settlement include increased tribal clashes, livestock rustling, and drought-induced livestock losses (Nori, 2023). The development of markets for camel products, especially milk-related goods through cooperatives, has contributed to improved income levels among the camel owners. The lactating camels remain closer to market networks even during the dry seasons, while other herds are relocated to far areas with forage. Pure dairy camel commercial farms have also developed in the area owned by wealthy traders, and the camels are kept within reach of the town year-round. These camels walk long distances within the ranches to graze on forage and access water at specific points, and there is no supplementation of feed (Nori, 2023). This pattern of the shift in nomadic pastoralism is expected to continue, similar to other countries (Nori, 2021). However, the counties with the largest populations of camels, Mandera, Wajir, Garissa, Turkana, and Marsabit, are largely still within nomadic pastoralism systems with predictable movement routes during the dry season.



In comparison, the camel sector in the Middle East has undergone a notable transformation, shifting from extensive to semi-intensive and intensive production systems. Case studies from two Middle Eastern countries, Saudi Arabia and the UAE, have revealed high levels of intensification. The Bedouin system, based on camel mobility and pastoral grazing, is being replaced by capital-intensive camel farms in which feed is provided to camels and camel products are processed and sold on national and international markets. The camels are provided with feed and water throughout the year and are exercised to mimic their natural grazing behavior, which typically involves walking long distances for up to 8 h daily (Faye, 2013). Large-scale camel dairy farms have been established in the UAE and Saudi Arabia to produce, process, and distribute camel milk. Milking machines have also been utilized in these intensive camel farms (Nagy *et al.*, 2013).

The growth of the modern camel industry in the Middle East is rooted in the recognition of the deep cultural significance of Bedouins' heritage and their social status, which has been driving capital investment in research and development of new technologies from both, the government and wealthy citizens. The diversification of camel roles has led to the rise of two economically significant activities: camel racing and beauty contests, in addition to camel meat and milk production. These roles have also been transformed through technological advancements in genetic selection and management of the camels to enhance performance and physical appearance (Bridi and De Man, 2025). The intensification of dromedary camel production is expected to continue as global demand for camel products increases, driven by perceived nutritional and health benefits (Nagy *et al.*, 2022). However, the likelihood of full intensification in Kenya's pastoral

communities remains low, as such enterprises require substantial capital investment to establish paddocks and milking parlors, provide feed and resources, and provide training to build human capacity. Moreover, in desert rangelands, camels and humans coexist in a manner that supports human survival under extreme conditions, while exerting minimal pressure on grazing lands (Faye, 2013).

SELECTION AND MANAGEMENT OF BREEDING STOCK IN DROMEDARY PRODUCTION SYSTEMS IN KENYA

Due to decades of camel keeping, pastoralist communities possess indigenous knowledge, including traditional breeding management practices. In these traditional systems as in the case for Kenya, females are naturally bred to bulls (Gitao *et al.*, 2021). Although the genomic breeding value (GBV) of the selected breeding animals has typically not been estimated using genomic tools, some form of selection is still occurring. In currently ongoing focus group discussions to identify the breeding objectives of dairy camels in Kenya (Nabulindo *et al.*, in preparation), camel keepers declare to select the breeding animals based on (i) the parents or family lineage were resistant to diseases, (ii) more resilient especially during the dry season, and (iii) daughters whose dams produced more milk (compared to the rest of the herd).

In addition to parentage-based selection, bulls are often chosen through visual appraisal of scrotal size; larger scrota are more likely to be selected for breeding. Interestingly, this indigenous knowledge aligns closely with scientific methods. In scientific evaluations, scrotal circumference is used to select breeding males expected to produce higher sperm counts (Novotná *et al.*, 2022).

Beyond disease outbreaks, pastoralists face major challenges from calf mortality and scarcity of feed and water during droughts. Therefore, selection based on visual assessment and performance history is a practical and valid strategy in these environments. Inbreeding is managed by replacing breeding bulls just before their daughters in the herd reach puberty, demonstrating that pastoralists are aware of inbreeding risks and actively implement control measures (Gitao *et al.*, 2021).

PERFORMANCE OF CAMELS UNDER EXTENSIVE MANAGEMENT: CAMEL MILK AND MEAT PRODUCTION

The value of camel milk in pastoral communities extends beyond mere metrics; it is a vital livelihood. It is used for home consumption and sold to generate income as the camel milk market expands (Anderson *et al.*, 2012; Nori, 2023). Commodification of camel milk has put pastoralists at the center of the rapidly growing towns surrounding the camel keeping areas. The production of camel milk in Kenya has increased significantly over the past decade, driven by rising demands, advancements in camel rearing, and enhanced marketing efforts. According to FAOSTAT (2023) statistics, milk production in African dromedaries primarily depends on population size, as seen in the case of Kenya in 2021, where a reduction in milk production was associated with a decline in camel numbers due to a severe drought that resulted in the death of more than a million animals. This scenario could be directly linked to the lack of human interventions in breeding and production through the use of ARTs.

In Kenya, communities still rely on traditional breeding, with natural selection of daughters from highly productive dams being incorporated into the breeding stock. The outcomes of such selections are usually unpredictable, as the desired traits may not be inherited (Al Abri *et al.*, 2023). Through the introduction of artificial insemination and genetic testing, the camel owners can select individuals based on proven genetic data. The significant impact of genetic selection has been reported for camels in the UAE, with camel owners describing the efficiency and predictability of breeding through ARTs (Bridi and De Man, 2025). Since camel farmers in Kenya traditionally select for high milk producers within

their herds, we asked the following questions: (i) How can milk production be increased through genomic selection? (ii) What are sustainable interventions that can be applied in the current infrastructure in pastoral areas that facilitate the use of marker-assisted or genomic selection methods to select for milk yield?

Contrary to earlier reports suggesting that pastoralists show little interest in improving camels for milk production, our observations indicate a strong desire among pastoralists to enhance productivity and develop more resilient animals. This shift in mindset may be driven by climate change, as many farmers are transitioning from cattle to camel farming due to camels' resilience during prolonged droughts (Kagunyu and Wanjohi, 2014; Rahimi *et al.*, 2022). In Kenya, the "Somali" camel is the most preferred breed, valued for its high milk yield (Oselu *et al.*, 2022). Although genome-wide association studies (GWAS) have not yet been conducted in this or other Kenyan breeds, efforts to support traditional selection practices are warranted.

In addition to camel milk, the live camel market has grown significantly, with large herds exported annually to Arabian countries following efforts by the Kenyan government to strengthen export markets (Mahmoud, 2013; Trading Economics Data, 2022). Global demand for camel meat and milk products is also rising as more countries open their markets to them. The perceived health benefits of camel milk and meat have contributed to this growth, with notable increases in camel milk consumption during and following the COVID-19 pandemic (Nagy *et al.*, 2021).

A critical question arising from the expanding export of camels from Kenya and East Africa is whether current populations are sufficient to sustain this trade in the long term. Given camels' long reproductive cycles and low reproductive performance relative to population growth rates, herd size is likely the limiting factor. Addressing this challenge requires exploring sustainable measures for semi-intensive and extensive camel farming systems, drawing lessons from successful breeding technologies applied in other livestock species, such as genomic selection (Weigel *et al.*, 2024). A consequent effect of intensification in the camel sector has been development, research, and the use of ARTs in the dromedary sector, as reported in the following section.

ARTS IN THE DROMEDARY: AI AND THE TECHNIQUE OF SEMEN COLLECTION AND PROCESSING

The first AI using long insemination tubes was reported in the Bactrian camel in 1961 (Elliot, 1961). However, over the past 30 years, the development of these techniques has gained momentum, with interest evident in improving dromedary production and performance traits such as milk, meat, and racing. This technique is important for reducing reproductive wastage, as it allows the use of a lower sperm concentration during insemination and enables semen to be frozen and shipped worldwide. One ejaculate from a bull is extended to make typically 2–3 semen doses. The use of AI eliminates the need for dairy herds to keep a breeding male, saving the cost of caring for males. AI can also reduce the transmission of venereal diseases, as bulls are screened for disease before semen collection, and the semen extender contains antibiotics. Lastly, once the semen has been cryopreserved in liquid nitrogen at -196°C , it remains viable for years. Therefore, bull semen can be available long after its death. For AI to be successful, the bull has to be trained for semen collection through using an artificial vagina (AV). Secondly, semen has to be extended to increase the number of doses. Thirdly, the female camel must be induced to ovulate prior to insemination (Skidmore *et al.*, 2013).

Semen collection is one of the main hindrances in the process of camel AI, due to the sternal recumbency mating behavior, which makes it challenging to direct the penis into the AV for collection. Furthermore, this species has a lengthy copulation of 5–10 min (El-Hassanein, 2017). A modified cattle AV has been successfully used to collect semen following teasing of a male by a female in estrus and diversion of the penis to the AV, the ejaculate is collected,

evaluated and extended (Skidmore *et al.*, 2013). Another device, the El-Hassanein camel dummy for semen collection documented success rates in semen collection (El-Hassanein, 2003, 2017). Generally, collecting a good semen sample requires expertise. Once the semen is collected, it is evaluated, which has also been a difficult barrier to overcome due to the camel semen being thick and viscous, which entraps the spermatozoa. The high viscosity is due to seminal plasma compositions, which contain secretions from the bulbourethral glands and the prostate, important for coitus and sperm fertility (Kershaw-Young and Maxwell, 2012). Evaluation of the sperm parameters is difficult to carry out until the semen is liquefied (Skidmore *et al.*, 2018). Despite the challenges, successful AI has been performed and a pregnancy rate of 53% (8/15) has been reported when 150 million motile spermatozoa were inseminated in the uterine body (Skidmore and Billah, 2005). Notably, pregnancy rates are affected by the number of spermatozoa inseminated and the site of insemination.

Among the many research articles and applications of ARTs, there were no reports on dromedaries in Kenya. For the African perspective, there were reports of camel-assisted reproductive technologies centers in Egypt and progressive research and applications done in this field with success in terms of semen collection, processing, and insemination (El-Hassanein, 2003, 2017; El-Bahrawy *et al.*, 2015; El-Bahrawy, 2017; Rateb *et al.*, 2019; Monaco and Lacalandra, 2020). In contrast to Kenya, the Middle East has been at the forefront of AI research and applications in camel breeding, with published data primarily from the UAE and Saudi Arabia. Several authors documented the success in the complex processes of AI: semen collection, semen processing, preservation, and the actual insemination process (Skidmore *et al.*, 2000; Hemeida *et al.*, 2001; Morton *et al.*, 2013; Skidmore *et al.*, 2013; Skidmore *et al.*, 2018; Al-Bulushi *et al.*, 2019; Cholakkal, 2019; Malo *et al.*, 2020; Mansour, 2022) (Table 3).

In addition to research on the technical aspects of AI in the dromedary, there have been reports of insemination success rates of 50–70% with fresh semen (Al-Bulushi *et al.*, 2019). In addition, pregnancies have also been obtained with the use of chilled or frozen-thawed semen (Morton *et al.*, 2011; Skidmore *et al.*, 2018). Despite reported success rates and extensive knowledge of the dromedary reproductive cycle, semen processing, and AI, large-scale commercial application of this technology has not been reported. A limitation of this could be the limited availability of semen doses and the widespread lack of technical expertise in semen storage and AI in camels (Monaco and Lacalandra, 2020). The reasons for the absence of similar ART research in other regions of Africa remains unclear. One possible explanation is a lack of government infrastructure and capital investment in the camel sector, resulting in insufficient resources and expertise to conduct research and implement new technologies.

USE OF ARTS IN THE DROMEDARY: IN VIVO, IN VITRO EMBRYO PRODUCTION, TRANSFER, AND CLONING

Embryo transfer (ET) is used to disseminate elite genetics by increasing progeny numbers from genetically proven males and females and shortening the generation interval. This technique can be fundamental in increasing camel production because, under natural conditions, camels have a long gestation period of 13 months, produce only five calves in their reproductive life, have a short breeding season, and require suboptimal reproductive management. Through embryo transfer, female camels' reproductive performance can be increased to five calves per year (Tibary *et al.*, 2005). Successful embryo transfer requires optimizing superovulation protocols for donors and synchronizing recipients. Superovulation involves the use of exogenous hormones, such as Follicle Stimulating Hormone (FSH), Equine chorionic gonadotrophin (eCG), and progesterone, to stimulate the ovaries to produce multiple ova in one estrous cycle. The timing for superovulation is very crucial, preferred when there is minimal follicular activity. The preparation and synchronization of recipients have a significant effect on the pregnancy rates. Better pregnancy rates are obtained when recipients are induced to ovulate 24–48 h behind the donor (Skidmore *et al.*, 2002).

There have been ongoing efforts to improve the efficiency of ET since the 1990s, but pregnancy rates (2-month pregnancy rate) remain low and variable, ranging from 21 to 42% of transferred embryos (Anouassi and Tibary, 2013; Osman *et al.*, 2025). There are still a lot of gray areas in research to elucidate the causes of the low pregnancy rates, including the recipients' uterine status, embryo quality, embryo toxic environment, etc. (Osman *et al.*, 2025).

Apart from the conventional ET, another more sophisticated ART that has been widely used to propagate offspring from genetically valuable females is *in vitro* production of embryos. This process involves collecting immature oocytes from the ovaries of live or slaughtered animals (ovum pickup) and maturing them in an appropriate culture environment. Following maturation, the oocytes are fertilized in the lab using viable spermatozoa. The resultant one-cell zygotes are cultured to develop into blastocysts, which are transferred to a synchronized female to carry the pregnancy to term. One of the main challenges in this process has been obtaining good-quality oocytes from the ovaries of slaughtered camels due to the lack of camel slaughterhouses. Further challenges include fertilization failure, a low percentage of zygotes developing into the blastocyst stage (16–20%), pregnancy losses, and other factors that require in-depth research in the mechanisms of embryo survival (Skidmore and Adams, 2000; Khatir and Anouassi, 2006; Osman *et al.*, 2025). In addition, a higher abortion rate from IVF embryo pregnancy has been reported in the first trimester. The first dromedary calf from *in vitro* obtained embryo was produced in the year 2005 (Khatir and Anouassi, 2006).

Table 3. Summary of assisted reproductive technologies in the dromedary research globally

ART	Country	Number of studies
Artificial insemination	United Arab emirates	10
	Saudi Arabia	2
	Africa (Egypt)	3
Embryo transfer	United Arab emirates	15
	Africa (Egypt)	2
Animal cloning	United Arab emirates	8
<i>In vitro</i> embryo production, <i>in vitro</i> fertilization and ovulation induction	United Arab emirates	2
	Africa (Egypt)	12

A more advanced ART reported in our literature search for dromedary camels includes animal cloning, also known as somatic cell nuclear transfer, which implies the production of genetically identical organisms (Wani *et al.*, 2010). The procedure involves the fusion of an enucleated oocyte with a somatic cell, followed by nuclear reprogramming of the somatic diploid nucleus to an undifferentiated totipotent embryonic state. The embryo is cultured until it undergoes cleavage and reaches the blastocyst stage, after which it is transferred to a surrogate mother. There have been debates about the sustainability of using this technology in camels, given that this species already has a narrow gene pool, and if used extensively, this technology would result in further loss of genetic diversity (Köhler-Rollefson, 2022), which may lead to increased susceptibility to certain diseases or abnormalities in camel populations. Genetic diversity ensures that species are constantly evolving to adapt to their local habitats and cope with environmental changes (Niasari-Naslaji, 2023). The first camel calf was produced by somatic cell nuclear transfer using cumulus cells of the dromedary camel in 2010 (Wani *et al.*, 2010). This process remains inefficient because many embryos are non-viable or produce abnormal offspring due to incomplete reprogramming and epigenetic modifications. A small number of cloned offspring have been produced in the last 10 years, but there is no clear published report on the survivability and the performance of the clones in racing, beauty contests or production (Niasari-Naslaji, 2023).

Notably, there was no report of research, use, or applications of *in vitro* embryo production and transfer in Kenyan dromedaries. Conversely, innovative research and application of *in vivo* and *in vitro* embryo production, transfer, and even cloning of dromedaries camels have been established in the Middle East, with a focus on the UAE and Saudi Arabia. The development of camel racing, the heavy capital investment in beauty contests, and the demand for camel milk products have increased interest in using ARTs to enable faster multiplication of elite animals through IVEP and the production of similar copies through cloning. Viewed collectively, few offspring have been produced from IVEP and cloning; however, *in vivo* produced embryos transferred to synchronized recipients have been shown to produce pregnancy rates of 65%, which is a significantly high percentage, indicating the progress in the development of this ET and its potential application to routine camel breeding (Tinson and Singh, 1998; Tinson *et al.*, 2001b; Skidmore *et al.*, 2004; Khatir and Anouassi, 2006; Khatir *et al.*, 2007; Niasari-Naslaji *et al.*, 2009; Wani, 2010; Skidmore and Billah, 2011; Anouassi and Tibary, 2013; Vettical *et al.*, 2016; Skidmore, 2018; Moulavi *et al.*, 2020; Skidmore *et al.*, 2020; Abouhefnawy and Wani, 2021; Olsson *et al.*, 2021; Skidmore *et al.*, 2021; Wani, 2021; Hossein *et al.*, 2024).

Within the African context, there have been studies reported in Egypt on various processes of embryo production ranging from optimization of induced ovulation, culture of oocytes, *in vitro* fertilization, and development of blastocysts (Badr and Abdel-Malak, 2010; El-Sayed *et al.*, 2015; Fathi *et al.*, 2018; Rateb *et al.*, 2019; Saad *et al.*, 2019; Khalifa *et al.*, 2020; Khatib *et al.*, 2020; Agag *et al.*, 2021). Despite progress in developing these techniques, they have been used minimally by camel breeders. From the Kenyan perspective, there have been no reported research studies in ARTs, which could be due to various barriers as elaborated in the next section.

Barriers in the integration and adoption of ARTs for the dromedary sector in Kenya

CHALLENGES IN INFRASTRUCTURAL FRAMEWORKS AND AVAILABILITY OF DATA ON BREED PERFORMANCE

The extensive pastoral systems present a significant impediment to the implementation of ARTs, especially due to animal mobility, and low financial investments are insufficient to sustainably cover the

cost of using advanced technologies. Even if camel semen doses were available, adopting AI would still be challenging due to the lack of infrastructure. AI requires reliable cold-chain and liquid nitrogen facilities for cryopreservation, which are scarce in the remote and marginalized regions of northern Kenya. Moreover, the nomadic nature of pastoralist communities complicates service delivery, as herders move in search of water and pasture during prolonged droughts (Faye, 2013; IGAD, 2023; Nori, 2023). The success of newly introduced technologies requires longitudinal studies to follow up on the camels and establish not only pregnancy rates but also the reasons for failure. Since AI depends on precise heat detection and timely insemination, these mobility patterns reduce its feasibility. Another barrier is the shortage of trained inseminators and veterinary professionals in camel production systems. Harsh climatic conditions, poor infrastructure, and insecurity discourage veterinary practitioners from settling in pastoral regions, leaving camel herders with limited professional support (IGAD, 2023).

The funding and government resources toward the camel sector and the communities have been minimal. The development of facilities is heavily reliant on international organizations, which leads to a lack of sustainability, especially after a funded project is complete (Nori, 2023). Additionally, there is limited data on the breeds and breed performance. Within the extensive productive systems, there is either no or very limited data recording. The absence of camel performance records databases is a significant barrier to the introduction of technology in these production systems; baseline information on the dams, sires, daughters, milk production, and reproductive indices are essential for building a breeding program.

Despite their critical role in sustaining livelihoods and enhancing resilience in drylands, camels remain underrepresented in scientific research and policy frameworks (Nori, 2023). The low level of research attention may be attributed to limited donor funding opportunities, logistical challenges associated with studying mobile pastoral systems, and the fact that large camel herds are concentrated in low-income countries, where research is often not prioritized by the relevant organizations. This article highlights the urgent need for greater investment and scientific attention in Kenya's camel sector. Strengthening research in ARTs and breed performance, as well as infrastructure and policy support, could unlock the full potential of camels as a sustainable resource in the face of climate change.

To overcome these barriers, a proposed holistic approach that balances the cultural significance of the camel, its role in supporting desert communities' livelihoods, and the level of ARTs that can be applied within the existing infrastructure is examined in the next section.

Overcoming barriers to the use and adoption of ARTs for the dromedary sector in Kenya

FEASIBILITY OF THE INTRODUCTION OF ARTS FOR DROMEDARIES IN KENYA

Due to increased land pressure, a shift in the grazing/pastoral system is expected as the human population grows and nomadic pastoralism among camel keepers transitions to a sedentary lifestyle. Researchers have suggested that a well-planned intensification of dromedary breeding in developing countries would increase technology investment in the sector and also enhance the integration of camels and their products in the food production chain (Faye, 2016; Nagy *et al.*, 2022). The commodification of camel milk has led to the establishment of a few camel dairy farms in Kenya. For example, Isiolo town has become a regional hub for the collection and transport of camel milk to other towns and the capital, Nairobi. This region has different types of camel owners;

some have fully commercialized camel herds, while others limit the movement of lactating camels near towns (Nori, 2023). Despite this being a small proportion of Kenya's camel herds, there is potential to introduce AI in these herds, especially since camel owners are already exposed to the commodification of camel products. Furthermore, such camel herds can be used for genomic selection studies, superovulation, and embryo transfer research.

While some advanced technologies may be too complex for extensive dromedary systems, specific approaches could be feasible. These range from conventional estimation of breeding values based on daughters' performance to genomic selection of the next generation of breeding stock using blood or hair follicle samples for genotyping. Implementing a genomic selection program, however, requires prior estimation of genomic breeding values through phenotyping and genotyping a reference population from a homogenous stock.

To identify the genotypes underlying various desired traits in Kenyan dromedary camels, a project for using genomic tools to characterize camel populations has been funded by a Coordinated Research Project (D31030) of the Joint FAO/IAEA Centre for Nuclear Techniques in Food and Agriculture, and we expect that the results of this project will be transformational. Such technologies could be applied in extensive production systems as camel keepers transition to more advanced reproductive technologies. Compared to cattle in Kenya, for instance, AI has revolutionized the dairy industry, resulting in a steep increase in milk production and the availability of high-grade, high-performing replacement heifers (Nathaniel Makoni *et al.*, 2015).

BRIDGING THE GAP BETWEEN THE USE OF ARTS AND THE CULTURAL-SPIRITUAL ROLES OF THE CAMEL IN KENYAN PASTORAL SYSTEMS

In addition to its products, the camel in Kenya is used in cultural and religious activities. Dromedary camels are used in dowry payments during marriage ceremonies, given as gifts, and as a symbol of peacemaking in tribal clashes (Guliye *et al.*, 2007). Among the livestock kept by pastoralists, camels were the most valued in focus group discussions with camel keepers in Kenya during our ongoing research study. The camel keeper community expressed strong reservations about using semen straws for breeding, emphasizing their preference for the physical presence of a bull. Whether this perspective will change in the coming years remains uncertain. However, the growing number of younger camel owners and wealthy camel traders with technological literacy may increase the likelihood of ARTs in the future.

Although there have been limited efforts by professionals to conduct research on breeding technologies in Kenyan dromedary camels, limited funding opportunities and socio-cultural norms within pastoralist communities have contributed to slow progress in research, hindering technology adoption. As much as pastoralists want more productive and resilient camels, they also want to retain the traditional roles and rearing style of camels. While professionals have sought to implement scientifically informed camel management practices, pastoralists have often resisted, emphasizing their indigenous knowledge of camel rearing, disease prevention, and overall management. Bridging this gap may require professionals to engage with and understand the culture of camel-keeping communities, leveraging local knowledge to develop strategies that facilitate the adoption of reproductive technologies as well as other innovations to enhance productivity.

INTEGRATING INDIGENOUS KNOWLEDGE WITH ADAPTIVE APPROACHES IN EXTENSIVE DROMEDARY SYSTEMS

In the extensive pastoralist camel keeping systems in Kenya, there are very few phenotypic data or production records available. This hinders advanced breeding programs, including genomic selection,

which depend on the availability of performance records for hundreds (or even thousands) of animals. Although the pastoralists do not record data in paper or digital form, they possess traditional knowledge passed down from generation to generation.

The application of reproductive technologies in intensive systems is definitely easier than in extensive systems. However, the intensification of any camel production system would be associated with additional costs of feeds, the cost of building feeding stalls, which would then require irrigation schemes and a higher amount of water usage (Faye, 2016). Additionally, the camel's physiology is well-adapted to the harsh conditions, and its ability to walk long distances to graze on low-energy-containing plants. Keeping such adapted animals in a restrained environment with high-calorie feed to improve production would present its own challenges, including those related to camel health and welfare. Moreover, it is essential to consider whether the unique adaptability of camels can be retained across future generations, especially under intensive systems. A further question is whether intensification will truly yield significant gains in milk yield relative to the costs incurred. Breeding technologies should aim to enhance production while safeguarding the dromedary's unique ability to thrive in harsh environments.

CONSERVATION OF ADAPTABILITY TRAITS VS GENETIC IMPROVEMENT FOR MILK PRODUCTION IN THE CAMEL

Before implementing technological interventions, it is essential to consider farmers' priorities and preferences for trait selection. In our ongoing research and focus group discussions, pastoralists consistently highlighted milk production as a primary concern. During the dry season, milk volume is critical because it is primarily consumed within households, with any surplus sold to generate income. In contrast, during the rainy season, milk production often exceeds demand, indicating that improvements along the camel value chain are also necessary.

While milk production remains important, farmers emphasized the need for resilient and adaptable camels that can withstand intensified desertification and emerging diseases, such as Middle East Respiratory Syndrome (MERS), while still producing adequate milk. These priorities differ markedly from intensive cattle systems, where genetic tools focus on selecting for high productivity. Understanding these farmer-driven preferences is crucial for designing interventions that are both effective and contextually appropriate in extensive camel production systems.

DESIGNING GENETIC SELECTION STRATEGIES FOR EXTENSIVE FARMING SYSTEMS IN KENYA

In the last 5 years, chromosome-level reference genomes have become available for dromedaries (Elbers *et al.*, 2019; Lado *et al.*, 2020) and Bactrian camels (Ming *et al.*, 2017). These genomic resources allow the identification of signals of selection for traits related to domestication (Fitak *et al.*, 2020), production (Bitaraf *et al.*, 2021), adaptation (Jirimutu *et al.*, 2012; Wu *et al.*, 2014), health (Ming *et al.*, 2020), and welfare. The calls to increase productivity in dromedaries in African countries are growing louder. However, it is imperative to involve the camel farmers of the community in defining their specific selection goals. For the development of selection or genetic improvement protocols applicable to extensive and semi-extensive breeding systems, it is essential to standardize: (1) animal identification, i.e., ear tag, electronic chip; (2) the systematic collection of phenotypic traits relevant for the selection goal, e.g., intermediate traits containing information on the milk or meat quantity and quality, growth rate, and health traits, including welfare parameters; and (3) appropriate genomic marker system, e.g., medium-high density SNP array or whole genome sequencing. Currently, there is one medium-density 50K SNP array for dromedary camels on the market, developed by Illumina offering an affordable cost of sequencing (Bruno *et al.*, 2023), and one camelid multi-species 180K SNP array by



Fig. 4. Steps for setting up a community-based breeding program. Source: Haile *et al.*, 2020. Available via license: CC BY-NC 4.0

ThermoFisher (Periasamy *et al.*, in preparation). To implement a genomic selection program in Kenya, it is important to identify sires and dams with high genomic breeding values. This can only be achieved by phenotyping and genotyping a reference population of at least 1000 dromedary camels. These animals should preferably come from a similar genetic background and be kept under similar conditions to maximize genetic and minimize environmental effects.

A complementary strategy for implementing selection protocols in accordance with local communities is the concept of a community-based breeding program (CBBP). The CBBP is an innovative breeding approach for genetic improvement and sustainable use of animal genetic resources in extensive farming systems (Haile *et al.*, 2020; Traoré *et al.*, 2021; Badjibassa *et al.*, 2023). By combining phenotype and genotype records (e.g., milk yield and growth rate) with local knowledge and farmers' cultural values, the best-producing sires and dams are identified, selected, and used for breeding within the community. The selection protocols developed in CBBPs have been successfully applied to African cattle (Traoré *et al.*, 2021), and sheep (Haile *et al.*, 2019; Haile *et al.*, 2020).

CONCLUSION

For a long time, the dromedary has been regarded primarily as a desert animal and, therefore, associated with marginalized communities. Yet, it has served as a crucial survival mechanism for pastoralists living in Kenya's arid and semi-arid areas. Despite this, the camel's importance has been underestimated, as its products account for only a small share of national GDP.

Preserving the unique physiology of the camel, which enables it to thrive under drought and harsh conditions, should remain central to breeding programs, complemented by production improvements

through appropriate reproductive technologies, particularly in extensive production systems in arid and semi-arid areas. There is significant potential to apply breeding technologies to accelerate genetic gain, enhance adaptability, increase disease resistance, and improve milk production. While advanced reproductive technologies such as artificial insemination, embryo transfer, or somatic cell nuclear transfer have been challenging to implement, this should not hinder efforts to sustainably improve camel production. Moreover, the introduction of ARTs into dromedary camel breeding programs must take into account the camel's sociocultural and spiritual significance within pastoral communities. Any commercialization driven by global market demand should be balanced to ensure that modern breeding innovations do not undermine traditional values or cultural identity.

The dromedary sector in Kenya is rapidly evolving and holds a significant promise. In the future, CBBPs may integrate genetic selection of high-performing dams and sires with phenotype-based selection methodologies, allowing productivity gains to be balanced with the dromedary's resilience and cultural significance within communities.

As milk markets expand and more camel dairy farms are established near major markets, these farms are increasingly likely to adopt digital tools such as mobile phone applications to document phenotypic performance data. Such records will be essential for genetic characterization and for developing nuclear herds composed of genetically proven, high-performing, and resilient dairy camels within pastoral systems. Given these changing dynamics in Kenya's dromedary production system, the application of ARTs is a realistic future step, particularly once the genetic characterization of dromedaries, currently underway in our project, is completed.

CONFLICT OF INTEREST

The authors declare no competing interests.

ETHICS STATEMENT

Not applicable.

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AUTHOR CONTRIBUTIONS

WNN conducted the literature search and wrote original manuscript; PB wrote the section on genetic selection strategies on the manuscript, reviewed and edited the manuscript.

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There is no data to report.

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