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Research on Camels at a Glance - Modest Review

Abdul Waheed* and Asim Faraz

Department of Livestock and Poultry Production, Faculty of Veterinary Sciences, Bahauddin Zakariya University, Multan, Pakistan

Corresponding author: drabdulwaheed@bzu.edu.pk

ABSTRACT

Camels (*Camelus dromedarius* and *Camelus bactrianus*) are among the most valuable livestock species inhabiting arid and semi-arid regions, where they play a crucial role in ensuring food security, sustaining pastoral livelihoods, and supporting rural economies. Their remarkable physiological and anatomical adaptations enable them to withstand extreme temperatures, prolonged water deprivation, and poor-quality feed resources, making them increasingly important under the challenges posed by climate change. This review synthesizes current knowledge on camel production, encompassing production systems, nutrition, growth performance, milk and meat production, reproductive biology, genetics and genomics, health management, and emerging technologies. Traditional camel production systems remain the backbone of pastoral communities in Africa and Asia; however, intensive and semi-intensive dairy systems are rapidly expanding, particularly in the Middle East, driven by growing demand for camel milk and its value-added products. Research has demonstrated that improved nutrition, health care, breeding strategies, and management practices significantly enhance productivity, reproductive efficiency, and product quality. Advances in molecular genetics, whole-genome sequencing, reproductive biotechnology, and precision livestock farming have created new opportunities for genetic improvement, disease control, and sustainable production. Camel milk has gained global recognition because of its high nutritional value and bioactive compounds with potential therapeutic benefits, while camel meat is increasingly valued as a lean and nutritious source of animal protein. Despite these advances, several constraints continue to limit the productivity of camel production systems, including inadequate genetic improvement programs, limited performance recording, poor veterinary infrastructure, feed scarcity, and weak marketing

systems, particularly in developing countries. Emerging research priorities include the application of genomic selection, artificial intelligence, sensor-based monitoring, precision nutrition, climate-smart management practices, and sustainable value chain development. Strengthening research collaborations, improving breeding and recording systems, and integrating modern technologies into traditional production systems are essential to fully exploit the production potential of camels. Given their resilience and adaptability, camels are expected to play an increasingly significant role in sustainable livestock production, food security, and climate change adaptation in dryland regions worldwide. This review provides a comprehensive overview of recent advances, identifies critical knowledge gaps, and outlines future research directions to enhance the productivity, profitability, and sustainability of camel production systems.

Keywords: Camels, research on camel, production, animal welfare

Camel Production Research

Camel production has attracted increasing scientific attention over the past three decades owing to the species' remarkable adaptation to arid and semi-arid environments and its growing importance in ensuring food security under changing climatic conditions. Traditionally regarded as a multipurpose livestock species providing milk, meat, transport, fiber, and draught power, camels are now recognized as climate-resilient animals capable of sustaining production under harsh environmental conditions where conventional livestock often fail. Research on camel production has expanded from descriptive studies of traditional management systems to advanced investigations involving nutrition, reproductive biotechnology, genetics, genomics, precision livestock farming, and sustainable production systems. The global camel population has continued to increase, particularly in Africa and Asia, where camels contribute significantly to the livelihoods of pastoral and agro-pastoral communities. Consequently, research institutions and international organizations have intensified efforts to improve camel productivity through better management, breeding, health care, and value addition (Faye, 2015; Alhajeri *et al*., 2019).

Camel Production Systems

Research on camel production systems has primarily focused on

understanding the diversity of management practices employed under pastoral, agro-pastoral, and intensive production systems. Traditional pastoral systems dominate camel production in countries such as Somalia, Sudan, Kenya, Ethiopia, Mauritania, Pakistan, and India, where camels graze natural rangelands and migrate seasonally in search of feed and water. Numerous studies have documented the resilience of these systems under extreme climatic conditions while also identifying constraints such as overgrazing, feed shortages, recurrent droughts, limited veterinary services, and poor market infrastructure (Faye, 2015, 2020). More recently, intensive and semi-intensive camel production systems have emerged in Gulf countries, including Saudi Arabia, the United Arab Emirates, and Qatar, where improved feeding, housing, mechanized milking, and reproductive technologies have substantially enhanced productivity. Comparative studies have demonstrated that intensive systems significantly increase milk yield and reproductive efficiency, although they require greater investment and technical expertise (Nagy *et al*., 2017).

Nutrition and Feeding Research

Nutrition has been one of the most extensively investigated areas of camel production. Early studies focused on the camel's exceptional ability to utilize poor-quality forages, browse species, halophytes, and desert shrubs. Researchers demonstrated that camels possess unique physiological adaptations allowing efficient digestion of fibrous feeds and prolonged survival under feed scarcity. Recent investigations have evaluated nutrient requirements during various physiological stages, including growth, pregnancy, lactation, and fattening. Protein supplementation, energy-rich concentrates, mineral mixtures, and strategic feeding during drought periods have consistently been shown to improve growth performance, reproductive efficiency, and milk production. Furthermore, studies have explored the use of agricultural by-products and non-conventional feed resources to reduce feeding costs while maintaining productivity, contributing to the sustainability of camel production systems (Faraz *et al*., 2019; Faye and Konuspayeva, 2018).

Growth Performance/ Meat Production

Growth performance remains a major research priority because of its direct relationship with meat production and profitability. Numerous studies have evaluated growth traits such as birth weight, weaning weight, average daily gain, mature body weight, and feed conversion efficiency across different camel breeds and production environments. These studies consistently indicate that growth performance is influenced by genetic background, nutrition, sex, age, season, and management practices. Improved feeding regimes and genetic selection have been associated with significant increases in daily weight gain and slaughter weights. Camel meat has also received considerable attention owing to its nutritional qualities, including high protein content, low intramuscular fat, lower cholesterol levels, and a favorable fatty acid profile. Research has further focused on carcass characteristics, meat tenderness, post-slaughter processing, and consumer preferences, highlighting camel meat as a promising alternative source of animal protein, particularly in regions affected by climate change and declining cattle productivity (Kadim *et al*., 2014; Faraz, 2020).

Camel Milk Production

Camel milk production represents the most extensively studied aspect of camel production due to its nutritional, medicinal, and commercial significance. Scientific investigations have examined milk yield, lactation curves, milk composition, udder health, milking management, and dairy processing technologies. Camel milk has been found to contain higher concentrations of vitamin C, essential minerals, protective proteins, and bioactive compounds than bovine milk, making it attractive for consumers seeking functional foods. Research has also demonstrated the antimicrobial, antioxidant, antidiabetic, and immunomodulatory properties of camel milk. Significant efforts have been directed toward improving dairy technologies for producing cheese, yogurt, fermented milk, and powdered camel milk, although processing remains challenging because of the unique physicochemical characteristics of camel milk proteins. The rapid expansion of commercial camel dairies in the Middle East has stimulated further research into milk quality, hygienic production, and value chain development (Konuspayeva *et al*., 2009; Faye and Konuspayeva, 2021).

Reproductive Performance

Reproductive efficiency has become another major focus of camel production research because of the species' relatively low reproductive rate compared with other domestic livestock. Investigations have examined puberty, reproductive seasonality, ovarian physiology, hormonal regulation, pregnancy diagnosis, calving intervals, and calf survival. Advances in reproductive biotechnology, including artificial insemination, embryo transfer, in vitro fertilization, ultrasonography, and semen cryopreservation, have opened new opportunities for genetic improvement and conservation of superior breeding animals. Although substantial progress has been made, reproductive technologies in camels remain less efficient than those in cattle because of species-specific reproductive characteristics, emphasizing the need for continued research (Skidmore, 2011).

Genetics and Genomic Research

The application of molecular genetics has transformed camel production research during the past decade. Early genetic studies focused on breed characterization using microsatellite markers and mitochondrial DNA, while recent investigations employ whole-genome sequencing, single nucleotide polymorphism (SNP) analysis, genome-wide association studies (GWAS), transcriptomics, and epigenetics. These approaches have identified genes associated with milk production, growth rate, adaptation to heat stress, disease resistance, and reproductive performance. Researchers have also emphasized the establishment of genomic selection programs to accelerate genetic improvement, although implementation remains limited because of insufficient pedigree recording and phenotypic databases in most camel-producing countries (Fitak *et al*., 2020).

Health and Disease Management

Maintaining animal health is essential for improving camel productivity, and considerable research has focused on infectious, parasitic, and metabolic diseases affecting camel populations. Common diseases investigated include camel pox, brucellosis, mastitis, trypanosomiasis, gastrointestinal parasitism, and tick-borne infections. The emergence of Middle East Respiratory Syndrome Coronavirus (MERS-CoV) further stimulated extensive research on camel health and zoonotic disease transmission. Current investigations

emphasize disease surveillance, vaccine development, molecular diagnostics, antimicrobial resistance, and integrated health management under the One Health framework. Preventive health programs have been shown to significantly improve production efficiency and reduce economic losses (Hemida and Alnaeem, 2019).

Climate Change and Sustainable Camel Production

One of the most rapidly growing areas of camel production research concerns climate change adaptation. Numerous studies have identified camels as one of the most climate-resilient domestic livestock species because of their remarkable ability to tolerate heat stress, prolonged water deprivation, and poor-quality feed resources. Their relatively low environmental footprint, efficient feed utilization, and capacity to produce milk and meat under extreme conditions have positioned camels as important contributors to climate-smart livestock systems. Researchers have suggested expanding camel production in drought-prone regions to enhance food security while reducing the vulnerability of pastoral communities to climate change (Faye, 2016; Faye *et al*., 2023).

Camel Welfare

Camel welfare has emerged as an important area of research in recent years, driven by growing public concern for animal well-being, increasing commercialization of camel production, and the expansion of intensive farming systems. Although camels have historically been regarded as highly resilient animals capable of surviving harsh desert environments, research has demonstrated that resilience should not be equated with good welfare. Like other livestock species, camels require appropriate nutrition, adequate housing, proper health care, humane handling, and freedom from pain, injury, and distress to achieve optimal welfare and productivity. The welfare of camels directly influences growth performance, reproductive efficiency, milk production, disease resistance, product quality, and overall economic returns, making it an essential component of sustainable camel production systems (Faye, 2013; Padalino and Menchetti, 2020).

Traditionally, camel welfare has been maintained under extensive pastoral systems where animals have unrestricted movement, natural grazing behavior, and social interactions. However, increasing urbanization, climate change, and

commercialization have resulted in the rapid development of semi-intensive and intensive production systems, particularly in the Middle East and North Africa. These systems expose camels to new welfare challenges, including restricted movement, prolonged standing on hard surfaces, overcrowding, transportation stress, inadequate ventilation, heat stress, poor hygiene, and inappropriate feeding practices. Several studies have shown that these stressors negatively affect physiological responses, immune function, reproductive performance, and milk production (Menchetti and Padalino, 2024).

Nutrition is a fundamental component of camel welfare. Although camels can survive prolonged periods of feed and water deprivation, chronic nutritional deficiencies reduce body condition, suppress immune responses, impair reproductive performance, and increase susceptibility to infectious diseases. Research has demonstrated that balanced diets containing adequate energy, protein, minerals, and vitamins significantly improve health, productivity, and welfare. Likewise, continuous access to clean drinking water, particularly under intensive management, contributes to improved physiological status and reduces heat stress (Faye and Konuspayeva, 2018).

Housing conditions also play a critical role in maintaining camel welfare. Modern camel farms should provide sufficient space for resting, walking, and social interaction while minimizing injuries associated with slippery floors, sharp structures, and overcrowding. Proper shade, ventilation, drainage, and bedding are essential for reducing thermal stress and maintaining comfort, especially in regions experiencing extreme summer temperatures. Studies have reported that camels provided with adequate shade exhibit lower respiration rates, improved feed intake, and enhanced milk production compared with animals exposed to direct sunlight for prolonged periods (Padalino and Menchetti, 2020; Faraz *et al*., 2024).

Handling and transportation are increasingly recognized as major welfare concerns. Poor handling practices, excessive restraint, rough loading and unloading, prolonged transportation without rest, and inadequate vehicle design induce significant physiological stress, as evidenced by elevated cortisol concentrations, increased heart rate, dehydration, and reduced immune function. Adoption of low-stress handling

techniques, appropriate training of animal handlers, and compliance with international animal welfare guidelines substantially improve animal well-being while minimizing production losses. Welfare assessment protocols developed for camels emphasize behavioral observations, body condition scoring, locomotion assessment, and physiological indicators such as cortisol, heart rate, and body temperature to objectively evaluate welfare status (Padalino *et al*., 2017).

Health management is another critical pillar of camel welfare. Preventive veterinary care, regular vaccination, parasite control, early disease diagnosis, prompt treatment, and effective biosecurity measures reduce morbidity and mortality while enhancing productivity. Pain management during surgical procedures, humane treatment of injured animals, and implementation of disease surveillance programs are increasingly regarded as essential components of ethical camel husbandry. Furthermore, improved welfare contributes to better product quality by reducing stress-related physiological changes that adversely affect milk composition and meat characteristics (Wernery, 2007).

International organizations such as the World Organization for Animal Health (formerly OIE) have increasingly emphasized the importance of welfare standards for camelids. The adoption of welfare principles based on the Five Freedoms and the more recent Five Domains Model provides a comprehensive framework for assessing nutrition, environment, health, behavior, and mental state in camels. These frameworks encourage producers to move beyond merely preventing disease toward promoting positive welfare experiences through appropriate environmental enrichment, social interaction, and good stockmanship.

Despite recent progress, camel welfare research remains limited compared with that of cattle, sheep, and horses. There is a need for standardized welfare assessment protocols specifically designed for camels, particularly for intensive dairy systems, transport, racing, and slaughter. Future research should focus on developing welfare indicators based on behavior, physiology, and precision livestock technologies, including wearable sensors, automated monitoring systems, infrared thermography, and artificial intelligence for continuous welfare assessment. Integrating

welfare considerations into breeding, nutrition, housing, and management strategies will not only improve the quality of life of camels but also enhance productivity, sustainability, and public acceptance of camel production systems.

Recently, few studies about camel welfare have been published in response to camel welfare projects in Pakistan funded by Animal Angels, Germany (Padalino *et al*., 2024; Faraz *et al*., 2025; Masebo *et al*., 2026 and Padalino *et al*., 2026).

Future Research Priorities

Despite substantial advances, camel production research continues to face important challenges. Reliable performance recording systems remain scarce, limiting the estimation of genetic parameters and the implementation of effective breeding programs. There is also limited application of precision livestock farming technologies, artificial intelligence, sensor-based health monitoring, and automated production systems. Future research should prioritize genomic selection, digital phenotyping, reproductive biotechnology, precision nutrition, disease resistance, environmental sustainability, and socioeconomic analyses of camel value chains. Strengthening international collaboration and increasing investment in camel research will be essential for unlocking the full production potential of this unique livestock species and ensuring its contribution to sustainable livestock production in the face of global climate change.

Table 1. Selected studies on camel production systems

Authors	Country	Research Focus	Major Findings	Contribution
Faye (2015)	Global	Camel production systems	Camel population is increasing due to climate resilience and food security demands	Established the global importance of camel production under climate change
Nagy *et al*. (2017)	UAE	Intensive dairy camel farming	Intensive management increased milk yield and reproductive efficiency	Demonstrated the commercial viability of modern camel dairies
Faraz *et al*. (2019)	Pakistan	Production potential	Better nutrition and management significantly improved growth performance	Provided production benchmarks for Pakistani camel production systems
Kena (2022)	Ethiopia	Camel production constraints	Feed scarcity and disease were the primary production limitations	Identified priority areas for intervention in pastoral systems

Table 2. Studies on camel growth performance

Authors	Breed	Variables Studied	Major Results	Contribution
Faraz *et al*. (2019, 2020*a*)	Marecha	Average daily gain	Improved nutrition increased growth rate by approximately 20–30%	Demonstrated the importance of concentrate supplementation
Kadim *et al*. (2008, 2014)	Omani camel	Carcass traits	Slaughter age significantly influenced carcass yield and meat quality	Provided standards for commercial meat production
Al-Saiady *et al*. (2012)	Arabian camel	Feed efficiency	High-energy diets improved feed conversion ratio	Established nutritional requirements for growing camels
Wilson (1998)	Various breeds	Growth parameters	Breed and management significantly influenced mature body weight	Early comprehensive review of camel growth biology

Table 3. Camel milk production research

Authors	Research Area	Major Findings	Significance
Konuspayeva *et al*. (2009)	Milk composition	Camel milk contains higher vitamin C and protective proteins than cow milk	Landmark meta-analysis on camel milk composition
Faye and Konuspayeva (2021)	Dairy production	Modern dairy management significantly increased milk yield	Improved understanding of commercial camel dairying
El-Agamy (2007)	Functional properties	Camel milk contains antimicrobial proteins and bioactive peptides	Highlighted therapeutic potential of camel milk
Alhaj and Kanhal (2010)	Nutritional quality	Camel milk is rich in unsaturated fatty acids and minerals	Supported the use of camel milk as a functional food
Faraz *et al*. (2020*b*, 2021*a*)	Milk production	Camel milk production is good in semi-intensive and extensive systems	Camel is life line in deserted areas

Table 4. Camel reproduction research

Authors	Research Topic	Major Findings	Contribution
Skidmore (2011)	Reproductive physiology	Detailed reproductive cycle and seasonality of camels	Standard reference for camel reproduction
Skidmore *et al*. (2013)	Artificial insemination	Improved conception rates under controlled management	Advanced reproductive biotechnology
Tibary and Anouassi (1997)	Embryo transfer	Successful embryo transfer protocols established	Foundation of assisted reproduction in camels
Wernery (2007)	Reproductive disorders	Identified major reproductive diseases affecting fertility	Improved reproductive health management

Table 5. Camel genetics and genomics

Authors	Research Area	Major Findings	Contribution
Fitak *et al*. (2020)	Whole genome sequencing	Identified genes associated with adaptation and production traits	Opened opportunities for genomic selection
Alhajeri *et al*. (2019)	Camel genomics	Heat adaptation genes identified	Explained molecular basis of desert adaptation
Wu *et al*. (2014)	Comparative genomics	Camel genome revealed evolutionary adaptations	First complete camel genome sequence
Burger (2016)	Population genetics	Identified genetic diversity among camel breeds	Useful for conservation and breeding

Table 6. Camel nutrition research

Authors	Research Topic	Major Findings	Contribution
Yagil (1985)	Water metabolism	Camels tolerate prolonged dehydration without major physiological disturbances	Classical work on camel physiology
Wilson (1989)	Browse utilization	Camels efficiently digest shrubs and desert vegetation	Established browsing ecology
Faye and Konuspayeva (2018)	Nutrient requirements	Energy and protein supplementation improved production	Modern feeding recommendations
Faraz *et al*. (2019)	Feeding management	Balanced diets increased daily weight gain and feed efficiency	Feeding strategies for Pakistan
Faraz *et al*. (2021*b*,*c*)	Water restriction and feeding management	Milk production was not affected by water restriction but with fodder provision	Water restriction studies enable camel as a food security candidate in changing climate

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