Galloping Towards Sustainability: Equine Breeding, Climate Change, and Resilience in the Mediterranean

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Abstract: Equine breeding plays a crucial role in the socio-economic and cultural landscape of Tunisia, particularly in the semi-arid Mediterranean region of the Kef governorate. This study aimed to classify and analyze the typology of equine breeding systems in this region, considering the environmental, economic, and management constraints breeders face. A structured survey was conducted between October 2021 and June 2022, targeting 50 breeders across 10 localities. Data was analyzed using descriptive statistics, Multiple Factor Analysis, and Hierarchical Clustering Analysis to classify breeding systems and identify their specific characteristics. Results revealed three distinct breeding systems: (1) Leisure and Traditional Games-Oriented Equine Farming (52%), integrating equines into rural cultural practices; (2) Racing and Competitive Equine Farming (46%), focusing on intensive performance breeding; and (3) Elite Breeding for Semen Production (2%), a highly specialized system emphasizing genetic selection and commercialization. The predominant feeding strategies included natural pasture, supplemented by barley, wheat bran, and vitamin-enriched feed. The study highlighted significant economic challenges, with 78% of breeders citing high feed costs and veterinary expenses as major constraints. A PESTEL analysis indicated that political instability, market fluctuations, and environmental constraints (low rainfall, and water scarcity) impact the sustainability of equine farming. A SWOT analysis identified the sector's strengths (cultural heritage, growing equestrian tourism) and weaknesses (poor market structure, lack of genetic improvement programs), alongside opportunities (development of structured breeding programs) and threats (climate change, increasing production costs).

In conclusion, structured breeding programs, cooperative farming models, and enhanced veterinary care are essential for ensuring the sustainability of equine farming in Tunisia. Future research should focus on optimizing breeding strategies, developing feed alternatives, and improving market access to enhance the economic viability of this sector.

Keywords: Equine ; Breeding ; Sustainability ; Mediterranean ; Semi -Arid

1   Introduction

Equine breeding holds a fundamental place in Mediterranean regions, where it plays a pivotal role in cultural heritage, economic activities, and rural livelihoods (Primi et al., 2024, Aroua et al., 2024, Myers, 2024). Throughout history, horses have symbolized prestige and tradition, deeply embedded in the social fabric of many Mediterranean communities (Pascual et al., 2024).Breeds such as the Barb and Arabian Barb have been particularly valued for their adaptability to arid climates, excelling in endurance, strength, and resilience under extreme environmental conditions (Redkey, 2014, Emerson, 2023). These breeds have historically served crucial roles in transportation, trade, and nomadic pastoralism, helping herders move livestock and goods across vast, arid landscapes (Aroua, 2020). Today, their utility extends beyond traditional uses, playing a growing role in tourism, equestrian sports, and agricultural work.

In Tunisia, horses are integrated into multiple sectors, reflecting a diversified equine economy. They continue to be used in traditional farming systems, where they serve as working animals for transportation and field labor (Allan, 2021, Jemmali et al., 2017). Additionally, the tourism sector heavily relies on equines for, cultural exhibitions, and traditional equestrian performances such as the "Fantasia" (Talley, 2017). This has created a demand for well-adapted local breeds, sustaining a network of small-scale breeders who integrate equine farming into broader agricultural (Moulin and Ickowicz, 2023).

Globally, equine breeding systems are typically classified into extensive and intensive models. In Europe, modern breeding is increasingly conducted in peri-urban settings, where land constraints dictate smaller-scale operations focused on sport, leisure, and racing (Rzekęć et al., 2020). Tunisia exhibits some similarities, particularly in desertic regions, where climatic constraints and land availability shape breeding strategies. The Arabian Barb, in particular, remains a cornerstone of Tunisia's equine industry, valued not only for its historical significance but also for its adaptability in modern applications such as tourism, endurance racing, and leisure riding.

Despite the growing economic importance of equine farming in Tunisia, limited research has been conducted to characterize its breeding systems systematically. A structured understanding of breeding typologies, management practices, and economic trends is crucial for sustainable development in the sector. Furthermore, with climate change posing increasing challenges, including rising temperatures, prolonged droughts, and feed shortages, the need for adaptive equine breeding strategies is more critical than ever.

This study aims to characterize and classify equine breeding systems in Tunisia, with a specific focus on the semi-arid Mediterranean region. By examining breeding practices, feed management, economic viability, and climate adaptation strategies, this research seeks to provide a comprehensive framework for understanding the sustainability of equine farming in a changing environment. Additionally, PESTEL and SWOT analyses will be used to assess macro-environmental influences and identify key opportunities and challenges in North-Tunisia's equine industry. Understanding these dynamics will aid policymakers, breeders, and stakeholders in developing sustainable, climate-resilient equine breeding models that support both economic growth and cultural preservation.

2   Materials and Methods

A survey was conducted to investigate the typology of equine breeding systems in the semi arid Mediterranean in the northeast of Tunisia- kef between October to June 2022. The primary objective of this study was to classify and analyze the breeding methods and strategies employed by local horse breeders in this semi-arid environment. A structured questionnaire was designed based on the framework established by (Aroua et al., 2021a). The survey targeted a representative sample of 50 breeders, covering the regions of Essers, Nebeur, Sidi Ahmed Salah, Kalaat Khesbat, Kalaat Senane, Kef EST, Tajerouine, Jerissa, Kef Ouest, and Dahmeni.
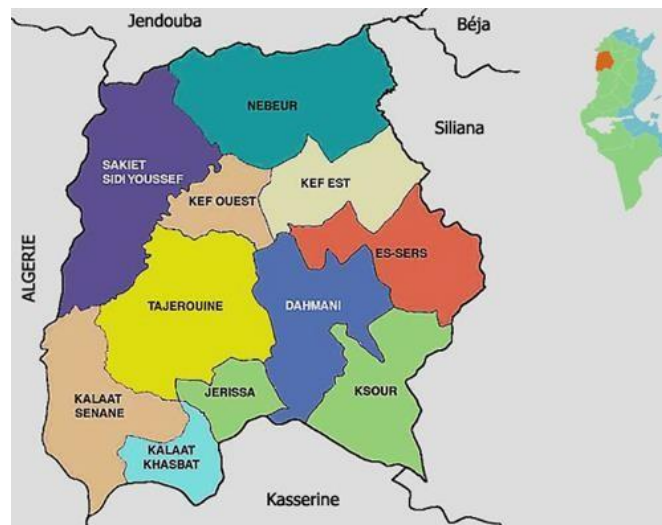

Figure 1. Study of area

The Kef region is characterized by a semi-arid Mediterranean climate, with hot, dry summers and cold, often snowy winters. Rainfall is limited, averaging between 400 and 500 millimeters annually. Temperatures fluctuate significantly, reaching up to 43°C in summer and dropping as low as -05°C in winter. The region experiences strong, dry winds like the sirocco, further intensifying summer heat. Given the challenging terrain, water scarcity, and harsh climatic conditions, local farmers have adapted their agricultural and livestock practices to ensure the sustainability of their operations.

The primary aim of this study was to collect in-depth information on the demographic profiles of horse breeders, their agricultural practices, feeding strategies, and the specific breeds they raise. The survey gathered key data on the breeders' age, educational background, and level of experience, providing valuable insights into their approach to equine management. Additionally, it explored herd composition, reproductive techniques, and feeding methods specifically adapted to the semi-arid Mediterranean climate, where water scarcity and harsh environmental conditions present significant challenges.

To ensure broad participation, a "snowball" sampling technique was utilized. This method began by identifying a small group of initial breeders, who subsequently referred other participants within their networks. This approach proved particularly effective in reaching farmers in isolated rural areas, where traditional word-of-mouth remains a crucial mode of communication. Given the geographical constraints and limited accessibility of certain regions, leveraging existing community ties facilitated the collection of reliable and representative data. (Geddes et al., 2018).

2.1   Statistical Analysis

A descriptive statistical analysis was conducted using Microsoft Excel 2007 to summarize the collected data. Following this, Multiple Factor Analysis (MFA) and Hierarchical Clustering Analysis (HCA) were employed to classify and differentiate the various equine farming systems identified in the study. These methods facilitated the categorization of breeders into distinct groups based on shared characteristics such as herd size, breeding techniques, feeding strategies, and adaptation methods to the semi-arid Mediterranean climate. The analyses were performed using XLSTAT software. (XLSTAT, 2013), ensuring a robust and data-driven classification of equine farming practices. Beyond statistical analysis, a PESTEL assessment examined the macro-environmental factors shaping equine farming in the region. Additionally, a SWOT analysis evaluated its internal strengths and weaknesses, as well as external opportunities and threats. By combining these analytical frameworks, the study offers a comprehensive perspective on equine farming, identifying key challenges while highlighting opportunities for sustainable development.

3   Results and discussion

The collected data highlight the importance of horse breeding in the Kef region, particularly in areas with a long-standing tradition of this activity. The highest equine populations are concentrated in four delegations—Dahmani, Sers, Kef ouest, and Kaalat Senane—where herd sizes can reach up to 10 mares in some cases. This finding indicates a shift from traditional breeding systems, where the number of mares per farm rarely exceeded two or three, toward an emerging trend of larger-scale equine farming. This evolution can be attributed primarily to the growing economic value of horses and their expanding uses. Given the increasing awareness of their economic impact on agricultural holdings, this trend is likely to continue in the coming years.

The surveyed breeders, exclusively male (100%), ranged in age from 17 to 75 years, with an average age of 38 ± 12 years. The majority had attained at least a secondary education and had received agricultural training (75%). Unlike other livestock farming sectors, horse breeding appears to require a minimum level of formal or professional education to ensure proper herd management. This necessity is likely due to the nutritional, health, and reproductive demands associated with equine farming, which require specific expertise to maintain the value and sustainability of the practice.

The total agricultural area (TAA) per farm averaged 18.9 hectares, with a significant variation among farms, ranging from 0 to 400 hectares (Table 6). While horse farming typically requires agricultural land, some breeders operate without any land holdings. This practice resembles the zero-grazing cattle farming system, commonly observed in Tunisia and elsewhere, but remains unusual for equine breeding in the Kef region.

The utilized agricultural area (UAA) averaged 17.3 hectares, closely aligning with the total agricultural area, indicating that uncultivated land within these farms is minimal. These results are consistent with findings from the National Agricultural Observatory (ONAGRI, 2023), which reported that small-scale farmers with less than 10 hectares own more than 65% of Tunisia's total equine population.

On average, 1.6 ± 1.2 hectares are allocated specifically for horse breeding. While this may seem sufficient, the effective land available per horse varies considerably between farms, emphasizing the need to consider the number

of horses per farm when assessing space allocation. Furthermore, land area alone is not a direct indicator of feed availability, as forage production depends heavily on the soil and climatic conditions of each region.

The predominant production system in the studied localities is the mixed farming system, which integrates agriculture and livestock. Livestock farming, primarily oriented towards subsistence, plays a crucial socio-economic role in the region. The main animal species raised by farmers include cattle, sheep, goats, horses, and poultry. Among these, small ruminant farming (sheep and goats) is the most widespread due to its significant economic and cultural importance in the Kef region.

This study confirms that sheep and goats constitute the largest livestock populations, particularly in northern Tunisia, where their breeding holds substantial economic value. They are followed by a significant number of cattle, primarily reared for milk and meat production. Regarding equine farming, the majority of surveyed farmers (70%) own only a small number of horses (< 4), except for equestrian centers and specialized breeders, where herd sizes exceed five individuals.

Agricultural activities in the region are dominated by cereal farming (64.3%), with barley, oats, and wheat being the most important crops, particularly in the Kef region, which has a long-standing tradition in grain production. Olive tree cultivation (38.4%) ranks second and is also a key economic activity in the studied localities. This sector has been expanding due to government incentives and the growing demand for olive oil, which is highly valued for its quality, largely attributed to soil composition and traditional olive varieties.

For economic reasons, small-scale farmers with less than 10 hectares tend to focus more on vegetable farming, particularly pepper, tomato, potato, garlic, and onion production. In contrast, farmers with larger land holdings (> 10 ha) typically adopt a diversified cropping system, combining cereal farming, olive tree cultivation, and vegetable production, ensuring greater economic stability. The forage calendar in the studied localities highlights the seasonal availability and distribution of feed resources, revealing a high degree of similarity in equine feeding strategies across regions. The feeding regimen primarily consists of natural pasture, wet barley, wheat bran, fenugreek, hay, straw, and multivitamin supplements (AMV), with the type of horse farming system significantly influencing feed distribution. Horses used for agricultural work and leisure are primarily fed hay year-round, complemented with barley soaked in water for over eight hours and/or wheat bran, improving digestibility and nutrient absorption to sustain energy levels for working horses(Vogedes, 2003). In contrast, racehorses and competition horses receive a more specialized diet, incorporating multivitamin supplements and fenugreek, catering to their higher energy expenditure and muscle recovery needs. The forage calendar indicates limited or no pasture utilization, suggesting that grazing is seasonally restricted or unavailable, likely due to semi-arid climatic constraints such as low precipitation and limited forage regrowth, necessitating reliance on stored feed resources (hay, straw, and cereals) for consistent herd nutrition. Wet barley and wheat bran are available year-round, reinforcing their role as primary energy sources for equines, with soaked barley improving digestibility and reducing the risk of colic(Harris and Dunnett, 2018, Davidson and Harris, 2007), particularly beneficial for intensely worked horses. Fenugreek, consistently included in the diet, provides digestive and metabolic benefits, stimulating appetite, improving nutrient absorption, and enhancing endurance, making it especially valuable for performance horses(Shen, 2016). The continuous provision of multivitamin supplements (AMV) reflects breeders' awareness of micronutrient importance, balancing potential dietary deficiencies in racehorses and working horses with higher physiological demands. Hay and straw, as primary fiber sources, are crucial for gut health, digestion, and preventing colic, with their continuous availability ensuring fiber intake stability, particularly in regions with limited natural forage. The nutritional strategy

aligns with existing literature on energy requirements, varying according to horse workload, with daily Feed Unit for Horses (UFC) values ranging from 4.9 UFC for resting horses to 7.9 UFC for those engaged in intensive work (Martin-Rosset and Tisserand, 2015). Given wide variations in workload and physiological demands, energy intake must be carefully adjusted to prevent deficiencies or excesses, with high-fiber roughage (hay, straw), energy-rich cereals (barley, wheat bran), and protein-rich fenugreek forming an adaptive feeding strategy to support both maintenance and performance horses. A major challenge in equine nutrition management lies in accurately calculating dietary intake, as feed quantities are often not precisely measured under farm conditions, affecting dietary energy and nutrient balance precision. This emphasizes the need for standardized feeding practices to ensure optimal performance and health. Despite this challenge, the feed composition observed in this study aligns with recommended nutritional guidelines, reinforcing equines' ability to efficiently utilize fibrous plant-based resources, justifying the heavy reliance on straw, hay, and pastureland, which not only maintain digestive efficiency but also optimize the use of locally available feed resources to reduce feeding costs. The lack of significant seasonal variation in feed composition suggests that horses are managed under a controlled feeding system, allowing breeders to maintain optimal body condition year-round. While this system ensures dietary stability, further improvements could include seasonal adjustments in feeding quantity and quality based on workload fluctuations, climatic variations, and forage availability(Brinkmann et al., 2012). Additionally, exploring alternative local feed resources with higher nutritional density could further enhance feeding efficiency and cost-effectiveness, particularly for racehorses and working horses with higher UFC and MADC demands.

Unlike donkeys, the health management of horses is not neglected, as evidenced by the comprehensive veterinary follow-up observed among all surveyed breeders. Equines receive regular veterinary care, with vaccination against rabies and colic being the most commonly administered preventive measures. This high level of veterinary oversight highlights the importance breeders place on maintaining equine health, particularly given the economic and functional value of horses in various activities such as agriculture, leisure, and competition(Aroua et al., 2021b).

The most frequently reported diseases in equine herds include colic, parasitic infections, and equine influenza. Colic, a potentially life-threatening gastrointestinal disorder, remains a major health concern, necessitating early detection and prompt intervention to prevent severe complications(Love et al., 2013). Parasitic infestations, particularly gastrointestinal helminthiasis, pose a significant risk to equine health, affecting nutrient absorption, growth, and overall well-being. Similarly, equine influenza, a highly contagious respiratory disease, can severely impact performance and productivity, making vaccination and biosecurity measures critical in equine herd management.

In addition to conventional veterinary treatments, traditional medicine remains widely practiced, particularly in remote or resource-limited settings. Many breeders use medicinal plants as alternative or complementary treatments for common equine ailments. For instance, eucalyptus, fenugreek, and coriander are commonly employed to combat gastrointestinal helminthiasis, leveraging their antiparasitic and digestive properties. Additionally, henna is frequently used as a dermatological remedy for treating skin conditions and dermatoses, benefiting from its antifungal and anti-inflammatory effects.

While traditional herbal treatments have been historically utilized for equine health, their efficacy and safety remain largely undocumented in scientific literature. Future research could explore the pharmacological potential of these botanical remedies, integrating ethnoveterinary knowledge with modern scientific validation to enhance equine healthcare practices. The combination of preventive veterinary care, vaccination programs, and traditional remedies

highlights a holistic approach to equine health management, ensuring optimal welfare and longevity in equine populations.

The equine population identified in this study consists of 69% mares and 31% stallions. The age range of mares within these farms varies from 36 to 200 months, with an average of 152 months. For breeding mares, the age at first foaling is approximately 53 months, aligning with established reproductive management practices. Male horses range in age from 120 to 240 months, with an average of 160 months. Although stallions reach puberty by two years of age, they are generally introduced to breeding at four years to ensure optimal fertility and physical maturity.

Natural mating occurs freely during the breeding season, predominantly in stations managed by the National Foundation for the Improvement of the Equine Breed (FNARC). The low proportion of male horses in agricultural farms is attributed to the breeding system and economic factors. According to the survey, 63% of breeders sell colts at an early age, primarily due to the challenges associated with raising young stallions and their lower economic productivity compared to mares.

Due to socio-cultural preferences, Tunisian consumers are not accustomed to consuming mare's milk, resulting in negligible production and commercialization. Consequently, most breeders allow foals to stay with their mothers throughout the lactation period, ensuring natural milk consumption. However, some breeders acknowledge the nutritional and medicinal benefits of mare's milk, particularly in the treatment of respiratory disorders, allergies, and infant nutrition. Despite these recognized benefits, the absence of a structured market and consumer demand significantly limits its commercial potential.

Survey data indicate that horses are utilized for multiple purposes, reflecting the diverse economic and cultural roles they play. Some breeders sell foals at an early age, particularly since natural mating is facilitated at FNARC stations. However, selling young foals at a premature stage often leads to their underutilization and low market value. Other breeders utilize horses for saddle riding, agricultural work, and competitive events, including beauty contests, racing, and equestrian sports. The multifunctional use of equines underscores their economic and cultural significance, yet market inefficiencies and limited valorization strategies highlight the need for improved equine management and commercialization frameworks.

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3.1 Characterization of Equine Farming Systems in the Kef Region

A Multiple Factor Analysis (MFA) was conducted to classify equine farming systems in the Kef region, with the first two principal factors accounting for 53.3% of the total variability. The first axis is strongly associated with parameters related to land area and herd size, with respective coordinates and contributions reaching 32%, highlighting the influence of land availability on equine farming practices.

The second axis, contributing 21% of the variability, is linked to variables associated with the reproductive age of horses, suggesting that breeding management practices significantly differentiate farming systems. The spatial distribution of breeders revealed the presence of three distinct groups; however, the degree of similarity or dissimilarity among them was not initially determined.
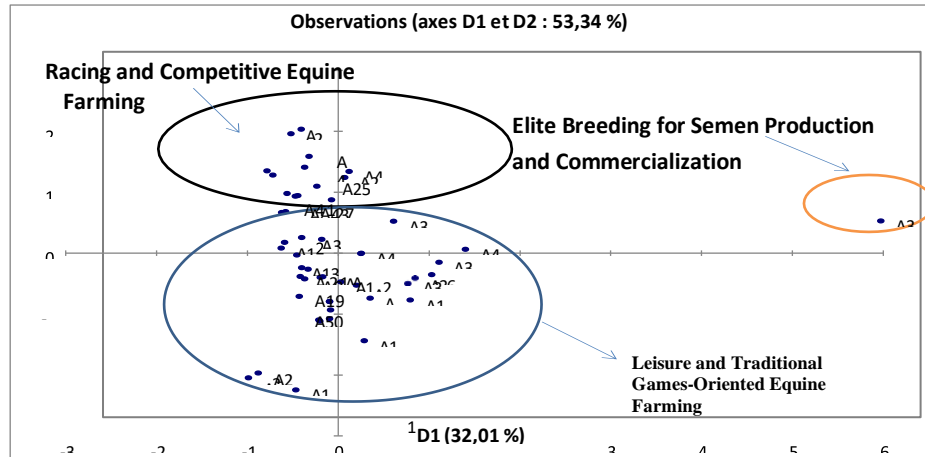
Figure 2 : Breeder distribution By MFA

To refine this classification, a Hierarchical Ascendant Classification (HAC) analysis was applied, leading to the identification of three distinct equine farming systems. These classifications provide a structured framework for understanding variations in breeding strategies, land use, and reproductive management, offering valuable insights for targeted policy interventions and resource allocation to improve equine farming efficiency and sustainability in the region.
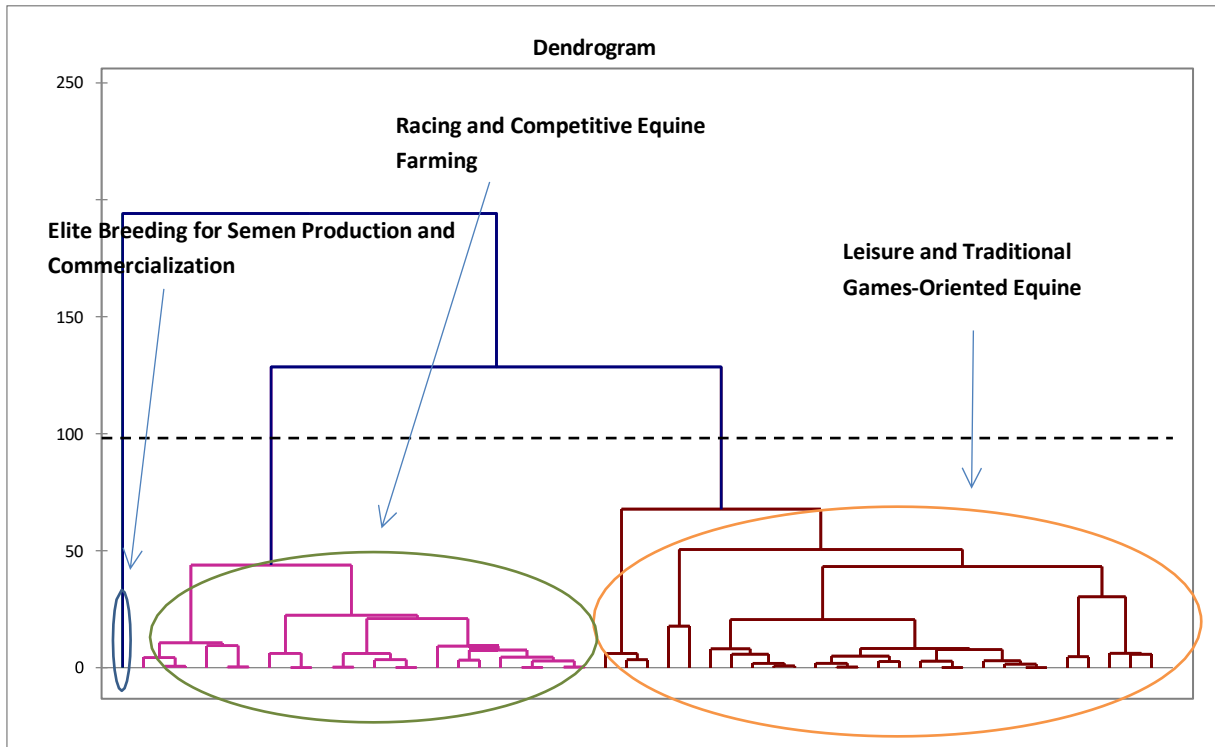

Figure 3 : Dendrogram By HCA

Cluster 1: Leisure and Traditional Games-Oriented Equine Farming

Representing 52% of breeders, this cluster consists mainly of small to medium-scale farmers who integrate equine farming into traditional rural lifestyles. These breeders operate on an average total agricultural area (TAA) of 11.2 hectares, with 1.8 hectares specifically allocated for horses. Herd sizes typically consist of five horses per farm, primarily of Arab-Barb (54%), Barb (44%), and Purebred Arabian (2%) breeds, reflecting the strong cultural heritage of equine breeding in Tunisia. Unlike specialized racing or elite breeding operations, horses in this system are primarily used for leisure, traditional games, agricultural labor, and ecotourism, making them an integral part of rural festivities and folkloric events. Management practices in this cluster emphasize natural breeding, with late foal weaning at around six months, allowing foals to benefit from extended maternal nutrition. Feeding strategies are relatively low-cost and pasture-dependent, supplemented with hay, barley, and wheat bran, with minimal reliance on specialized dietary supplements or veterinary care. Economically, this system remains modest in profitability but offers stability through multipurpose horse utilization, particularly in ecotourism and equestrian festivals. However, its limited commercial focus and lack of structured breeding programs pose challenges to genetic improvement and long-term economic viability. Despite these limitations, moderate land availability provides an advantage in maintaining natural grazing, reducing feed costs compared to more intensive breeding operations. Future development strategies for this cluster could include integrating equestrian tourism with rural heritage initiatives, encouraging selective breeding programs to enhance local horse quality, and implementing basic veterinary and nutritional optimizations to improve horse health and longevity.

Cluster 2: Racing and Competitive Equine Farming

Representing 46% of breeders, this cluster focuses on high-performance equine breeding for racing and competitive equestrian sports. Breeders in this category operate on an average total agricultural area (TAA) of 11.04 hectares, with a significantly smaller equine-designated area of 1.39 hectares, reflecting a more intensive and controlled management system. The herd composition primarily includes Barb (65%), Arab-Barb (33%), and Purebred Arabian (5%) breeds, selected for speed, endurance, and agility in competitions. Unlike traditional systems, early foal weaning (4.52 ± 0.58 months) is practiced to accelerate the growth and conditioning process, ensuring that young horses adapt early to specialized training regimens. Feeding strategies in this cluster rely heavily on high-energy diets, including barley, alfalfa, protein concentrates, and vitamin-enriched supplements, to enhance muscle development and performance. The higher financial investment in nutrition, training facilities, and veterinary care distinguishes this cluster from leisure-oriented breeding. Economically, this system has higher revenue potential, particularly for successful racehorses and those sold to professional equestrian centers. However, the high cost of maintenance, reliance on structured training, and financial risks associated with race performance pose significant challenges. Additionally, the intensity of early training and selective breeding increases the risk of strain injuries and shorter career longevity for some horses. Future development strategies for this cluster should focus on enhancing breeding programs for genetic optimization, investing in specialized equine sports medicine, and developing sustainable training methodologies to maximize performance while minimizing health risks. Expanding research on optimal nutritional strategies could also improve energy efficiency and endurance in competitive horses, strengthening Tunisia's position in the international equestrian industry.

Cluster 3: Elite Breeding for Semen Production and Commercialization

This cluster, representing only one breeder, is a highly specialized, large-scale breeding system focused on elite genetic selection, semen production, and international racehorse development. Operating on an exceptionally large total agricultural area (TAA) of 400 hectares, with 4 hectares allocated specifically to equine breeding, this system accommodates a substantially larger herd, consisting of 20 mares, 8 stallions, and 12 foals. The primary breeds raised in this system are Purebred Arabian and Thoroughbred English horses, selected for elite genetic traits and competitive racing performance. Unlike other breeding systems, this cluster practices late foal weaning at approximately 8 months, ensuring that foals develop stronger immunity and skeletal structure before transitioning to structured diets. The breeding process is highly controlled, with artificial insemination and semen collection conducted at FNARC's Sidi Thabet breeding station, ensuring high reproductive efficiency and quality control. In addition to genetic enhancement, horses from this system are trained for elite-level competitions at Ksar Said racing club, where they compete in prestigious national and international events. The economic viability of this system is highly lucrative, as semen sales and high-value racehorses generate significant revenue. However, the investment costs in specialized breeding facilities, advanced veterinary care, and genetic research are extremely high, making this system accessible to only a few elite breeders. Additionally, maintaining international breeding standards and ensuring genetic quality require continuous scientific advancements and selective breeding programs. To further strengthen this system, strategic development efforts should include international partnerships in equine genetics, investment in advanced reproductive technologies, and expanding Tunisia's global footprint in elite equestrian breeding and racing. Establishing collaborations with genetic research institutions could enhance the efficiency of artificial insemination and embryo transfer technologies, positioning Tunisia as a competitive hub for high-performance equine genetics.

3.2   The Role of Equine Farming Clusters in Climate Change Mitigation and Economic Development

The three equine farming clusters in the Kef region—Leisure and Traditional Games-Oriented (Cluster 1), Racing and Competitive (Cluster 2), and Elite Breeding for Semen Production (Cluster 3)—not only have environmental implications but also possess the potential to contribute positively to climate change mitigation and serve as a financial source for breeders if organized within civil, community, or local society frameworks. By promoting sustainable equine farming practices, cooperative breeding programs, and eco-friendly land management, these clusters can reduce climate risks, enhance biodiversity conservation, and generate economic resilience for local communities.

Each cluster, if well-organized and managed under community-driven sustainable models, can play an active role in mitigating climate change through carbon sequestration, sustainable grazing, and efficient feed production (Johnston and Spring, 2021). Cluster 1, which relies on natural pastures and traditional horse-keeping methods, can serve as a carbon sink if pasturelands are managed under regenerative grazing practices (Furtado et al., 2022). By preventing overgrazing and restoring degraded lands, these equine farms can increase soil organic matter, enhance water retention, and improve carbon sequestration, effectively counteracting climate-related desertification in semi-arid regions like Kef (Saba et al., 2024).

For Cluster 2 and Cluster 3, adopting sustainable feed production and circular waste management systems could significantly reduce greenhouse gas (GHG) emissions (Symeon et al., 2025). Incorporating agroforestry in pasturelands, using organic compost from manure as a fertilizer substitute, and promoting locally sourced feed alternatives can lower carbon footprints while making the sector more resilient to climate-induced feed shortages (Amole and Ayantunde, 2016). Moreover, integrating renewable energy sources such as solar-powered stables and biogas production from equine waste can further decrease the environmental impact of high-performance equine farms (Wang et al., 2023).

Beyond environmental benefits, these clusters can become important financial sources for breeders if integrated into cooperative models, community organizations, or local societies. In many regions, unstructured equine farming limits financial growth due to market inefficiencies, lack of commercialization, and absence of cooperative funding mechanisms (Challa et al., 2019, Bedane, 2016). However, by transitioning into organized community frameworks, breeders can access collective funding, government subsidies, and international sustainability initiatives that support climate-friendly and economically viable livestock production systems.

For Cluster 1, which primarily involves traditional and leisure-oriented horse breeding, formalizing into rural cooperatives or heritage equestrian associations can unlock eco-tourism opportunities, attracting both local and international visitors interested in experiencing cultural horseback riding, equestrian events, and sustainable agrotourism. By establishing community-owned equestrian centers and organizing traditional horse festivals, this cluster can generate revenue through tourism, equestrian training schools, and breeding programs, transforming a low-profit sector into a sustainable business model.

For Cluster 2, which focuses on racehorses and equestrian competition, developing regional equestrian clubs and training academies within cooperative structures can increase financial sustainability and market competitiveness. Currently, many individual breeders face high financial risks due to unstable racehorse sales and unpredictable performance outcomes. If community-led investment funds or equine breeding cooperatives were introduced, breeders could share training costs, reduce individual financial burdens, and collectively benefit from revenue-sharing agreements with equestrian event organizers and betting companies. Additionally, partnerships with eco-friendly sports organizations could provide grants and sponsorships for equestrian centers that commit to low-emission horse farming.

For Cluster 3, which operates at the elite breeding and semen production level, transitioning into a cooperative breeding network could provide access to global equine genetics markets while ensuring financial stability through pooled resources and collective marketing strategies. Rather than individual breeders managing high-cost breeding operations independently, community-based elite breeding hubs could facilitate international breeding collaborations, offer artificial insemination services to smaller breeders, and improve genetic diversity through controlled breeding programs. Establishing a Tunisian National Equine Genetics Consortium, supported by local and international stakeholders, could create a globally recognized breeding program, increasing the country's export potential and ensuring long-term economic resilience for breeders.

If equine farmers were organized within civil society frameworks, they could qualify for government support, development grants, and NGO funding aimed at promoting sustainable agriculture and climate adaptation (Morahanye, 2020). Governments worldwide are investing in green livestock initiatives to encourage low-emission, environmentally friendly animal husbandry (Thornton et al., 2024, Islam, 2024). Equine farming in

Tunisia could benefit from public-private partnerships that support carbon-neutral equestrian businesses, including incentives for eco-friendly training facilities, sustainable feed production, and manure-based biofertilizer projects. NGOs focusing on biodiversity conservation and rural development could also assist in restructuring equine farming models, providing financial aid and technical expertise for sustainable land management and regenerative equestrian practices. Programs promoting carbon offset credits for horse farms practicing sustainable grazing and organic manure management could offer additional income streams for breeders while contributing to global carbon reduction efforts (Neethirajan, 2024, Singh et al., 2024).

4   Conclusion

This study provides a comprehensive analysis of equine breeding systems in the semi-arid Mediterranean region of northeast Tunisia, specifically in the Kef region. By classifying breeders into distinct clusters—leisure and traditional games-oriented, racing and competitive, and elite breeding for semen production—the research highlights the diversity of equine farming practices and their socio-economic significance. The findings underscore the adaptability of breeders to the region's challenging climatic conditions, employing tailored feeding strategies, reproductive techniques, and land-use patterns to ensure sustainability.

Despite the growing economic value of equine farming, challenges such as limited access to structured breeding programs, inconsistent feed availability, and market inefficiencies remain. Implementing cooperative breeding models, promoting sustainable feed production, and integrating modern veterinary practices could enhance the sector's long-term viability. Moreover, fostering government and NGO support for organized equine cooperatives may offer financial and environmental benefits, aligning with global efforts toward climate resilience and rural economic development.

Future research should explore optimized feeding strategies, genetic improvements, and innovative management techniques to enhance productivity while ensuring environmental sustainability. By leveraging local expertise and international collaborations, equine farming in Tunisia can evolve into a more structured, profitable, and resilient industry.

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