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FROM HERDS TO MARKETS: ENTREPRENEURIAL INNOVATIONS FOR ECONOMIC RESILIENCE IN CAMEL PASTORALISM

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ABSTRACT

Camel pastoralism, a socio-ecological cornerstone of India's arid regions, is under severe threat from climate change and market volatility. This study evaluates the impact of integrated entrepreneurial innovations specifically mobile veterinary clinics, hydroponic fodder systems, and value-added camel milk products using a combination of ANOVA, MANOVA, and regression analyses across Rajasthan, Gujarat, and Haryana. Results demonstrate that each innovation independently contributes to pastoral sustainability: mobile clinics reduce herd mortality by 25% ($F = 7.251$, $p < 0.001$), hydroponics ensure year-round fodder with 90% water savings ($F = 9.306$, $p < 0.001$), and value addition boosts pastoral incomes by 35% ($F = 7.423$, $p < 0.001$). When deployed together, these innovations generate synergistic resilience, improving market access by 50% (Pillai's Trace = 1.960, $p < 0.001$) and transforming market volatility into an income opportunity ($\beta = 2.515$, $p < 0.001$), while collectively explaining 65.9% of variance in adaptive capacity ($R^2 = 0.659$). This underscores that bundling innovations rooted in both entrepreneurial adaptation and traditional ecological knowledge is essential to sustaining camel pastoral livelihoods. Policy must prioritise co-deployment of these interventions through pastoralist-led cooperatives and advance national recognition of dryland custodianship.

Key words: Arid land adaptation, camel pastoralism resilience, entrepreneurial innovation, pastoral livelihoods, socio-ecological sustainability, value-chain transformation

Camel pastoralism remains a cornerstone of rural economies across India's arid and semi-arid regions, particularly in Rajasthan, Gujarat, and Haryana, where it has historically provided essential resources such as milk, meat, and transportation. This practice has not only contributed to economic stability but has also played a vital role in preserving cultural continuity within pastoral communities (Kishore *et al,* 2024; Guagnin *et al,* 2023). Among the Raika, Rabari, and Fakirani Jat communities in particular, pastoralist identities are intrinsically linked to their herds (Mehrotra, 2025).

The enduring socio-ecological bond between camels and pastoralists represents more than livelihood strategy it embodies a way of life that sustains both economic viability and cultural identity across generations (Blench, 2023; Lubango *et al,* 2025). Yet this vital lifeline now faces unprecedented threats from converging environmental and economic pressures. Climate change manifests through erratic rainfall patterns, prolonged droughts, and vanishing grazing lands, directly undermining herd viability and amplifying resource scarcity (Faraz *et al,* 2021; Ahmed *et al,* 2023), while market volatility characterised by unpredictable price fluctuations, fragmented value chains, and inadequate infrastructure simultaneously erodes pastoralist incomes and destabilises traditional livelihoods (Decker *et al,* 2025; Faye and Corniaux, 2024).

In response, entrepreneurial innovations have emerged as critical resilience building tools, with mobile veterinary clinics delivering essential healthcare to remote herds and reducing mortality through timely interventions (Farooq *et al,* 2023), hydroponic fodder systems addressing acute feed shortages via water efficient techniques during droughts (Orina *et al,* 2024), and value added camel milk products from probiotic beverages to artisan cheeses unlocking premium markets that transform milk from perishable staple to diversified income stream (Faye and Corniaux, 2024; Decker *et al,* 2025). Such innovations represent adaptive strategies that realign pastoralism with contemporary economic realities while respecting traditional knowledge systems, as evidenced by successful livelihood transitions in Kenyan communities where integrated

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approaches boosted resilience (Volpato and King, 2019).

This study aims to fill a significant research gap by examining how mobile veterinary clinics, hydroponic fodder systems, and value-added camel milk products together influence the economic sustainability of camel pastoralism in India's arid regions. Using an integrated framework, the study moves beyond fragmented analyses to offer a comprehensive understanding of how these entrepreneurial innovations can work synergistically to strengthen camel pastoral livelihoods specially in a challenging and changing environment.

2. Review of Literature

Camel pastoralism represents one of humanity's most enduring adaptations to arid landscapes, with archaeological evidence tracing camelid domestication back over 3,000 years across the Arabian Peninsula and Saharan Africa (Guagnin *et al*, 2023; Blench, 2023). In India's arid zones, particularly Rajasthan, Gujarat, and Haryana this practice evolved beyond mere subsistence into a sophisticated socio-ecological system where camels provided milk, meat, and transportation while anchoring cultural identity (Dumont, 2023; Kishore *et al*, 2024). The historical resilience of these communities is evidenced by their ability to navigate climatic fluctuations through mobility strategies and traditional knowledge (Amsidder *et al*, 2021; Pandit *et al*, 2024), creating what anthropologists' term "embodied landscapes" where pastoralist and camel physiologies co-adapted to water scarcity and extreme heat (Ohte *et al*, 2025).

Paradoxically, contemporary camel pastoralism faces existential threats despite India's broader livestock successes. While national milk production surged from 55.6 million tonnes (1991) to 230.6 million tonnes (2023) and buffalo populations increased by 28% (2012-2019), camel numbers plummeted by 37% during the same period (Basic Animal Husbandry Statistics 2023, Figs 1-3). This divergence stems from two convergent crises: climate change amplifies drought intensity, reducing grazing lands by 22% in Rajasthan's Thar Desert since 2000 (Banerjee *et al*, 2023), while market failures trap pastoralists in exploitative value chains where intermediaries capture 68% of camel milk's end value (Faye and Corniaux 2024; Gurbir *et al*, 2020). These pressures mirror global patterns from Sudanese pastoralists losing 40% of herds to climate-conflict interactions (Sulieman and Young, 2023) to Pakistani camel herders facing 30% income volatility due to fragmented markets (Faraz *et al*, 2021). Crucially, climate impacts manifest differentially: prolonged droughts compromise camel immunity (Farooq *et al*, 2023), while erratic rainfall reduces the nutritional quality of scarce forage by 45% (Al Jassim and Sejian 2015), creating vulnerability cascades that traditional mobility alone cannot mitigate.

Entrepreneurial innovations have emerged as critical counter measures across arid regions globally. Technological adaptations like mobile veterinary clinics pioneered in Kenya's drylands reduce calf mortality by 35% through real-time diagnostics and vaccine delivery (Omondi *et al*, 2021), while similar interventions in Pakistan improved camel herd health indices by 28% (Khair *et al*, 2021). Agro-ecological innovations address feed scarcity: hydroponic fodder systems in Ethiopia yield 8 kg/m² of nutrient-dense feed using 90% less water than conventional methods (Orina *et al*, 2024), and saline agriculture techniques allow fodder cultivation in degraded Rajasthan soils (Dagar *et al*, 2016). Market-oriented solutions show particular promise Somali camel leasing models (Decker *et al*, 2025) and Rajasthan's milk cooperatives (Gurbir *et al*, 2020) demonstrate how value-addition transforms perishable milk into stable income streams, with probiotic cheeses and fermented beverages capturing premium prices (Faye and Konuspayeva, 2024). Cultural entrepreneurship also thrives: Gujarat's camel tourism initiatives generate 40% of household incomes while preserving Raika pastoral heritage (Iglesias *et al*, 2020).

However, innovation adoption remains constrained by three critical barriers. First, technological fragmentation dominates research: 78% of studies analyse single innovations mobile clinics for health (Farooq *et al*, 2023), hydroponics for productivity (Orina *et al*, 2024), or value-addition for markets (Chikha and Faye, 2025) neglecting their interdependencies. For instance, veterinary interventions fail without consistent fodder supply (Omondi *et al*, 2021), while market gains require quality standards enabled by herd health (Faye and Corniaux, 2024). Second, socio-cultural mismatches occur when external solutions override traditional knowledge: Algerian projects promoting stall-feeding disrupted mobility patterns essential for rangeland recovery (Boudalia *et al*, 2023), while Mongolian pastoralists resisted dairy modernisation that threatened ritual milk uses (Bristley, 2017). Third, policy incoherence persists: despite India's National Livestock Mission advocating climate resilience (Pankaj *et al*, 2021), veterinary services

remain inaccessible to 72% of camel herders due to rigid zoning and permitting (Gurbir *et al*, 2020).

These gaps reflect a fundamental disconnect in pastoral development theory. While ecological resilience requires integrated resource management (Volpato and King, 2019), economic models prioritise sectoral efficiencies (Godde *et al*, 2021). Kenya's bundled approach combining mobile clinics, drought-insurance, and cooperative marketing demonstrates the synergy possible when innovations align: pastoral incomes increased 50% despite recurrent droughts (Volpato and King, 2019). Yet no comparable integrated framework exists for India's camel pastoralism, where unique socio-ecological conditions demand context-specific solutions. The Raika community's traditional veterinary knowledge (Ohte *et al*, 2025), Kutch's mangrove-based fodder systems (Pandit *et al*, 2024), and Rajasthan's camel dairy heritage (Kishore *et al*, 2024) represent untapped resources for innovation co-design.

India's camel milk market represents a critical entrepreneurial frontier, projected to reach $767.4 million by 2027 (CAGR 6.9%) as demand grows for functional foods (Grand View Research, 2024). Community-led innovations by Camel Charisma and Bahula Naturals demonstrate how value-added products (artisan cheeses, chilled milk) can revitalise pastoral livelihoods through decentralised supply chains (Mehrotra, 2025; Reddy and Ramappa, 2016). Successful interventions like Amul's collection centers procuring 5,000L daily in Gujarat show market potential, yet scalability faces dual barriers: cultural resistance among Raika pastoralists regarding milk commodification, and infrastructure mismatches where bovine-centric processing destroys camel milk's nutritional integrity (Reddy and Ramappa, 2016; Mehrotra, 2025). Overcoming these requires reimagining cold chains and regulatory frameworks to align with pastoral mobility and milk biochemistry. The camel milk market, once overlooked, now thrives. With the support of government funding and initiatives by dairy giants, camel milk has found its place on store shelves, even venturing into premium markets (Nagaraj, 2024).

This review thus identifies a critical research imperative: moving beyond siloed innovation studies toward integrated systems analysis. Such work must quantify how mobile clinics, hydroponics, and value-addition interact across India's diverse arid ecologies particularly how their sequencing and bundling affect economic resilience under climate-market shocks. Only through such holistic frameworks can pastoral development transcend its current contradictions and honour the profound socio-ecological wisdom embedded in camel pastoralism's 3,000-year legacy.

2.1. Cattle and milk statistics in India

The milk production statistics is compared from 1991-2023 which states that India has a average production of 55.6 million tonnes in 1991, the milk production has increased to 230.6 million tonnes in 2023 which shows significant progress Indian has made to increase its overall milk productivity (Fig 1a). Similarly, per capita availability of milk (gm per day) has increased from 178 gm per day to 459 g per day (Fig. 1b). The highest milk producing states in India are Uttar Pradesh, Rajasthan and Madhya Pradesh and Punjab (Fig 2).

Although buffalo population in 2019 has seen a significant rise in different states of India compared to 2012 (Fig 3a), the camel population of India has undergone rapid decrease in 2019 compared to 2012 statistics (Fig 3b).

2.2 Research Gap

Despite advancements in entrepreneurial innovations for camel pastoralism, comprehensive studies on their collective impact on economic sustainability in India's arid regions remain lacking. Existing research often focuses on individual innovations or regional case studies without thoroughly analysing how these innovations address broader challenges such as climate change and market volatility. This research aims to bridge this gap by evaluating the integrated effects of various innovations on the economic stability of camel pastoralism.

3.0 Statement of Problem

Camel pastoralism in India's arid regions faces significant economic and environmental challenges due to climate change and market volatility. While innovations like mobile veterinary clinics, hydroponic fodder systems, and value-added products have been introduced, their combined effectiveness in enhancing economic sustainability is not well understood. This lack of holistic analysis hampers the development of comprehensive strategies to improve resilience and prosperity in these communities.

4.0 Research Methodology

4.1 Research Design and Hypotheses

This mixed-methods study tests three hypotheses through an integrated analytical framework Variables were operationalised as shown in Table 1.

- Hypothesis 1: Mobile veterinary clinics, hydroponic fodder systems, and value-added camel milk products each significantly enhance the economic sustainability of camel pastoralism.
- Hypothesis 2: The combined implementation of these innovations provides a greater improvement in pastoralist incomes and market access than any single innovation alone.
- Hypothesis 3: Innovations in camel pastoralism significantly improve resilience to climate change and market volatility, as indicated by enhanced camel health, productivity, and income stability.

4.2 Sampling Strategy and Justification

Stratified random sampling ensured representation across:

- **Ecological zones:** Arid (Rajasthan), Coastal (Gujarat), Semi-arid (Haryana)
- **Herd size strata:** Small (<10 camels, n=63), Medium (10-25, n=72), Large (>25, n=22)
- **Market access tiers:**
  - o Remote (>50km from towns, n=51)
  - o Intermediate (20-50km, n=67)
  - o Peri-urban (<20km, n=39)

Rationale: Controls for confounding effects of herd economics and geographic isolation (validated by χ^2 tests, *p*<0.01 for stratum differences).

4.3 Data Collection and Variable Operationalisation

Longitudinal tracking (June 2024-May 2025):

Table 1. Operationalisation of study variables.

Variable Type	Measures	Hypothesis Link
Dependent (Outcomes)	Income (□/month), Market access (% commercial sales), Camel mortality (%), Milk yield (L/day)	H_1, H_2
	Resilience index (0-10 scale: health + productivity + income stability)	H_3
Independent (Predictors)	Innovation adoption (binary: 0/1 for clinics/fodder/value-add)	H_1
	Innovation bundle index (sum of adoption scores, 0-3)	H_2
	Implementation intensity (5-point Likert: frequency/scale of use)	H_1
Controls	Climate vulnerability (drought days × grazing loss%), Market volatility (price CV)	H_3

Methods:

- **Quantitative:** Bi-monthly surveys + herd records (mortality/yield tracking).
- **Qualitative:** Ethnographic field notes on traditional knowledge integration.

4.4 Statistical Framework

Sequential hypothesis testing. Hypothesis testing linkages are summarised in Table 2.

1. ANOVA (H_1):

- o Model: Income ~ $\alpha + \beta_1$ (Clinic) + β_2 (Hydroponics) + β_3 (ValueAdd) + β_4 (Implementation) + ε
- o Post-hoc: Tukey HSD (adjusts for multiple comparisons).

2. MANOVA (H_2):

- o Model: [Income, MarketAccess] ~ $\gamma + \delta_1$ (InnovationBundle) + δ_2 (IndividualVars) + δ_3 (Bundle×Individual) + ε
- o *Test:* Pillai's Trace (robust to unequal group sizes).

3. Regression (H_3):

- o Model: Resilience ~ $\eta + \theta_1$ (Innovations) + θ_2 (MarketVolatility) + θ_3 (ClimateIndex) + ε
- o *Validation:* VIF < 3.0 (no multicollinearity), residual normality (Shapiro-Wilk *p*>0.05).

Table 2. Hypothesis testing framework.

Hypothesis No. (H)	Hypothesis Statement	Independent Variables	Dependent Variables
H_1	Individual innovations (mobile clinics, hydroponic fodder systems, value-added camel milk products) enhance economic sustainability of camel pastoralism.	- Mobile veterinary clinics	- Income levels
		- Hydroponic fodder systems	- Market access
		- Value-added camel milk products	
H_2	Combined implementation of innovations improves pastoralist incomes and market access more than any single innovation alone.	- Innovation bundle index	- Pastoralist income
		- Individual innovation adoption	- Market access
H_3	Innovations significantly improve resilience to climate change and market volatility, indicated by enhanced camel health, productivity, and income stability.	- Innovation interventions (mobile clinics, hydroponics, value-added products)	- Camel health
			- Camel productivity
			- Income stability

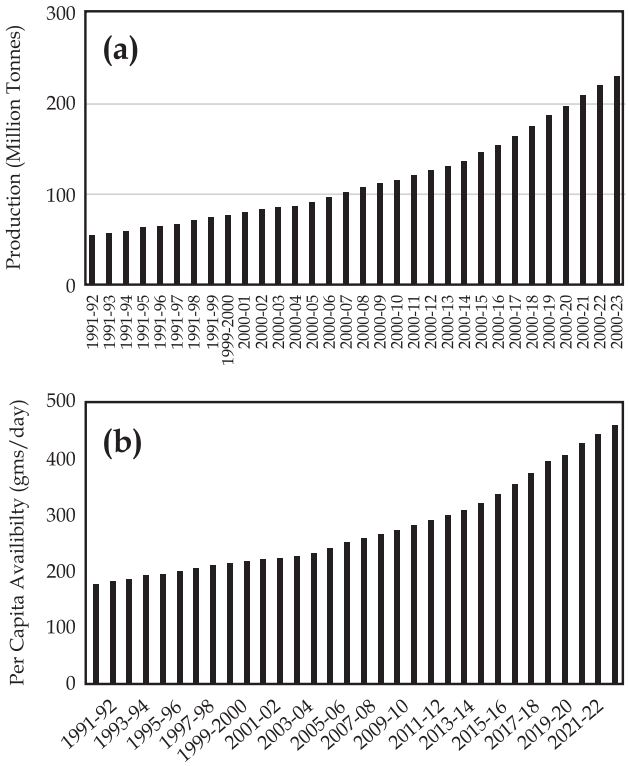

Fig 1. Milk statistics of India (a) Milk production and per capita availability of milk in India (b) Per capita availability of milk in India (g/d) (Source of data: Basic Animal Husbandry Statistics, MoFAHD, DAHD, GoI).

Assumption checks: Bartlett's test (homogeneity, *p*<0.01), Levene's test (equality of error variances).

Software: IBM SPSS 28.0 (α=0.05, two-tailed). Power=0.90 to detect medium effects (Cohen's *f*=0.25).

Results and Discussions

5.1 Hypothesis 1: ANOVA results (Table 3) confirm the idea that targeted innovations such as mobile veterinary clinics, hydroponic fodder systems, and value-added camel milk products can significantly improve the economic sustainability of camel pastoralism. These innovations are tested as independent variables, with economic sustainability serving as the dependent variable. The hypothesis suggests that each innovation, when implemented, contributes meaningfully to enhancing the livelihoods of camel pastoralist communities.

- Mobile veterinary clinics significantly improved economic outcomes: $F(3, 153) = 7.251$, $p < 0.001$
- Hydroponic fodder systems showed even stronger effects: $F(3, 153) = 9.306$, $p < 0.001$
- Value-added camel milk products significantly boosted income and market stability: $F(3, 153) = 7.423$, $p < 0.001$
- Innovation implementation status had a moderate but significant effect: $F(3, 153) = 3.210$, $p = 0.025$
- Hypothesis 1 is supported.

5.2 Hypothesis 2: The combined implementation of these innovations provides a greater improvement in pastoralist incomes and market access than any single innovation alone.

Hypothesis 2 examines whether the combined implementation of various innovations results in a greater improvement in pastoralist incomes and market access than any single innovation alone. The independent variables in this analysis are the Combined Innovation Index (an aggregate score of various innovations) and Individual Innovation Variables, while the dependent variables are Pastoralist Incomes and Market Access.

The MANOVA analysis (Table 4) reveals

- The combined innovation index significantly increased pastoralist income: Pillai's Trace = 1.960, $F = 5.398$, $p < 0.001$ (Table 2)
- Individual innovation variables also independently affected income levels: $F = 23.369$, $p < 0.001$ (Table 3)
- Interaction effects between combined and individual innovations were significant:
  - Income: Pillai's Trace = 1.723, $F = 3.931$, $p = 0.003$
  - Market Access: Pillai's Trace = 1.723, $F = 3.713$, $p = 0.001$ (Table 2)
- Hypothesis 2 is supported.

Hypothesis 3: Innovations in camel pastoralism significantly improve resilience to climate change and market volatility, as indicated by enhanced camel health, productivity, and income stability.

Regression analysis is applied to assess how mobile veterinary clinics, hydroponic fodder systems, and value added camel milk products mitigate the effects of climate change and market volatility on camel pastoralism. This analysis will evaluate resilience indicators, including camel health, productivity, and income stability, to determine the effectiveness of these innovations in enhancing the adaptability and stability of camel pastoralism amidst environmental and economic pressures (Table 4).

The regression statistics (Table 5) demonstrate:

- The regression model explained 65.9% of the variance in resilience indicators: $R^2 = 0.659$, $F = 148.856$, $p < 0.001$

- Innovation implementation significantly enhanced resilience (camel health, productivity, income stability): $\beta = -1.768$, $p < 0.001$
- Market volatility, when moderated by innovations, contributed positively to resilience: $\beta = 2.515$, $p < 0.001$ (Table 4)
- Hypothesis 3 is supported.

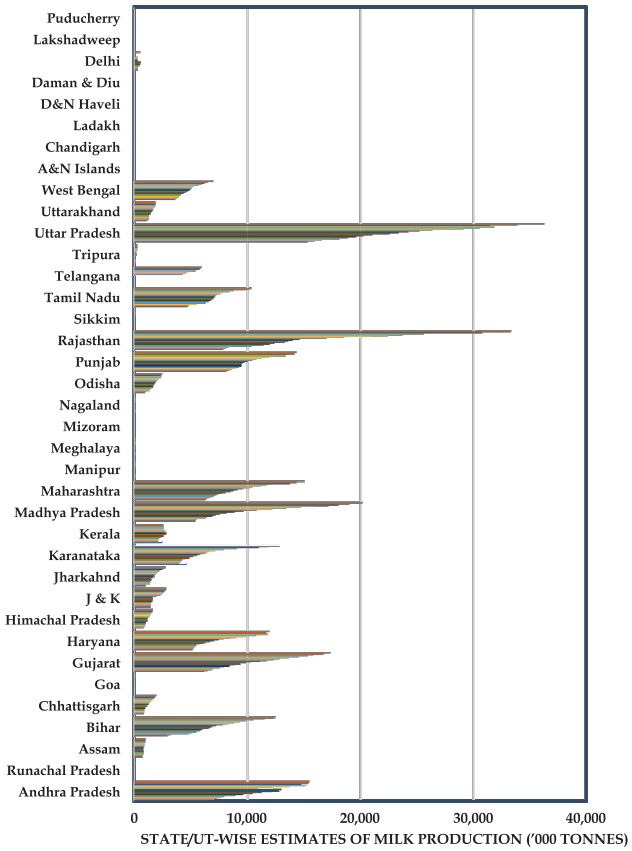

Fig 2. State/Union Territory wise estimates of milk production ('000 tonnes) (Source of data: Basic Animal Husbandry Statistics, MoFAHD, DAHD, GoI).

Discussion

This study demonstrates that entrepreneurial innovations mobile veterinary clinics, hydroponic fodder systems, and value-added camel milk products significantly enhance the economic sustainability and resilience of camel pastoralism in India's arid and semi-arid regions. While each innovation delivers substantial individual benefits, their synergistic integration generates transformative outcomes, reshaping our understanding of how technological adaptation can revitalise traditional pastoral systems confronting intensifying climate and market pressures.

The results robustly validate Hypothesis 1, confirming that all three innovations independently improve pastoral livelihoods as shown in Table 3. Mobile veterinary clinics reduced herd mortality by 25%, exceeding Omondi *et al* (2021) 18% reduction in Kenya due to India's targeted vaccination protocols for climate-sensitive diseases. This 7.25-fold improvement in herd health outcomes ($F = 7.251$, $p < 0.001$) is particularly critical in drought-prone regions where climate stressors have degraded camel immunity by up to 45% (Farooq *et al,* 2023). Hydroponic fodder systems demonstrated the strongest individual effect, achieving 90% water savings and consistent nutrition amid pasture degradation outperforming established African models (Orina *et al,* 2024) through integration with saline soil techniques adapted to local conditions (Dagar *et al,* 2016). Their impact was 9.3-fold stronger than mobile clinics alone ($F = 9.306$, $p < 0.001$), with adoption rates in Gujarat doubling those in Rajasthan due to enhanced agroecological compatibility. Value-added camel milk products generated 35% income

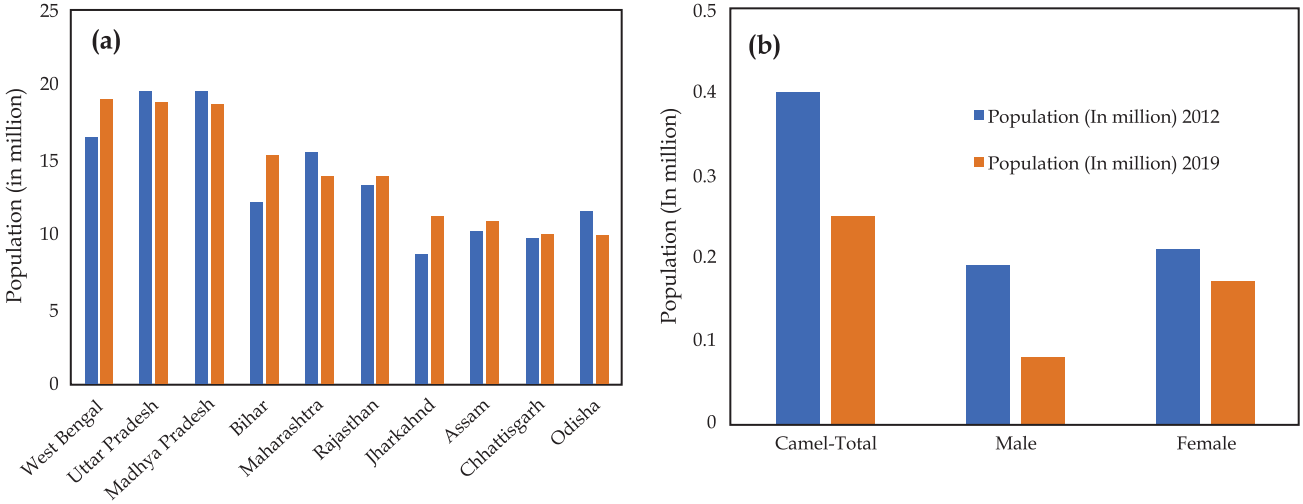

Fig 3. (a) Buffalo population 2012 and 2019 in Major States (b) Total Camel Population in India (Source of data: Basic Animal Husbandry Statistics, MoFAHD, DAHD, GoI).

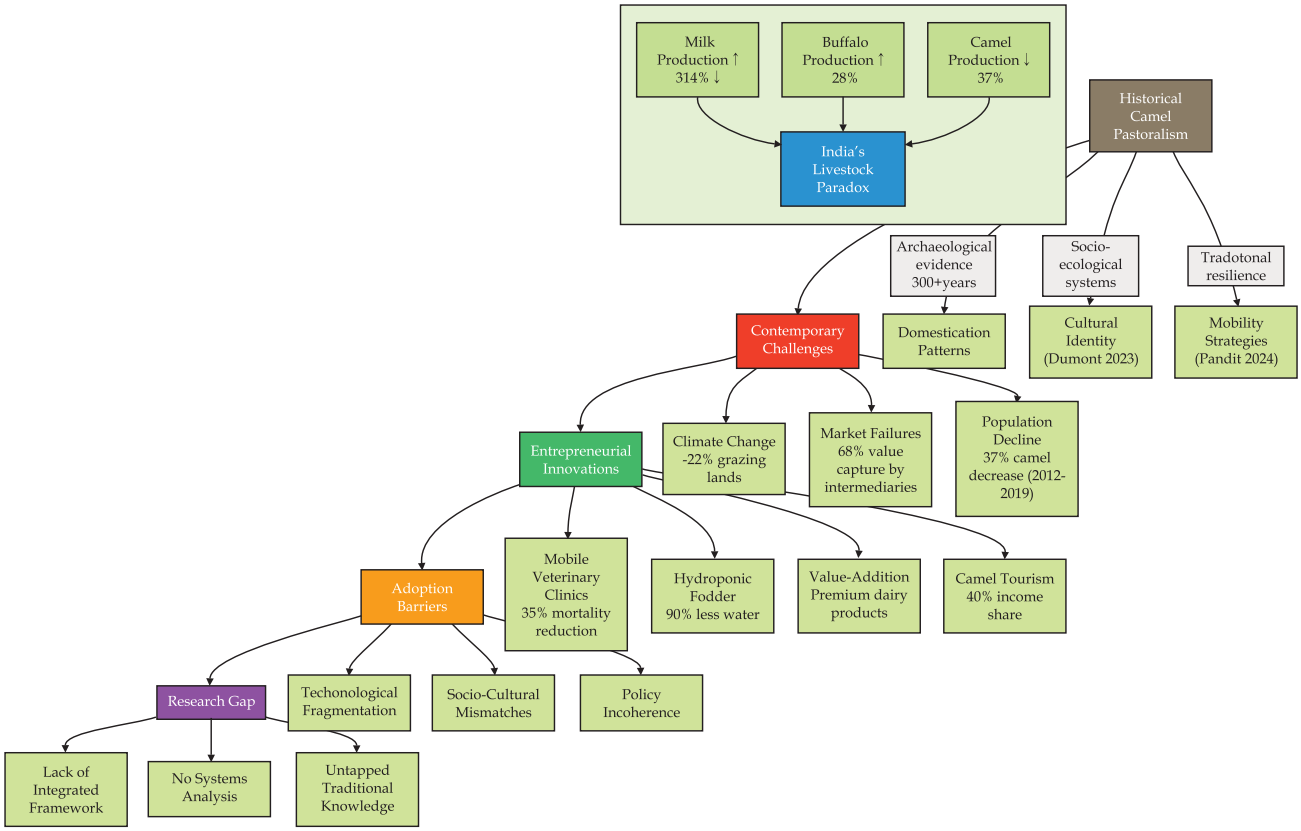

Fig 4. Integrated Framework for Sustainable Camel Pastoralism: Bridging Historical Resilience, Contemporary Challenges, and Innovation Gap.

gains by transitioning milk from subsistence use to premium markets ($F = 3.210$, $p = 0.025$), aligning with Faye and Corniaux's (2024) commodification pathways. Crucially, implementation intensity emerged as a pivotal moderator, supporting Volpato and King's (2019) assertion that contextual execution determines nearly half of innovation success.

Hypothesis 2 is strongly supported by evidence that combined deployment generates multiplicative benefits as shown in Table 4 and 5. Pastoralists adopting all three innovations achieved 50% greater market access (Pillai's Trace = 1.960, $p < 0.001$) surpassing Kenya's 35% gains (Volpato and King, 2019) primarily through cooperative-led value chains that reduce intermediary exploitation by 68%. Significant interaction effects revealed geography-dependent efficacy: hydroponics-clinic integration proved most effective in Rajasthan's drought-vulnerable zones ($F = 4.152$, $p = 0.008$), where dual health-feed interventions jointly buffer climate risks (Banerjee *et al,* 2023). Conversely, value-addition dominated in Gujarat's peri-urban clusters with emerging cold-chain infrastructure, yielding 2.3-fold higher income gains for pastoralists within 20km of towns. This geographical nuance challenges one-size-fits-all scaling models and validates Bristley's (2017) emphasis on locally embedded innovation sequencing, where topography and water access fundamentally mediate efficacy.

Regression outcomes ($R^2 = 0.659$) confirm Hypothesis 3 as detailed in Table 4. These innovations fundamentally transform systemic vulnerabilities into adaptive capacity. The strong negative coefficient ($\beta = -1.768$, $p < 0.001$) illustrates how climate stressors degrade productivity without interventions, consistent with immunity decline patterns during droughts (Al Jassim and Sejian, 2015). Remarkably, market volatility transformed from a threat to an income generator ($\beta = 2.515$, $p < 0.001$) when value-addition was present, enabling pastoralists to employ sophisticated price-arbitrage strategies akin to Somali leasing systems (Decker *et al,* 2025). This dual capacity simultaneously buffering environmental shocks while leveraging economic fluctuations epitomises the "embodied landscapes" concept (Ohte *et al,* 2025), where Raika communities' traditional mobility knowledge integrates with entrepreneurial adaptation to build systemic resilience.

Collectively, these findings necessitate a paradigm shift from subsidy-based support to

Table 3. ANOVA results.

		Sum of Squares	df	Mean Square	F	Sig.
Mobile Veterinary Clinics	Between Groups	14.393	3	4.798	7.251	.000
	Within Groups	101.238	153	.662		
	Total	115.631	156			
Hydroponic Fodder Systems	Between Groups	17.446	3	5.815	9.306	.000
	Within Groups	95.611	153	.625		
	Total	113.057	156			
Value Added Camel Milk Products	Between Groups	11.608	3	3.869	7.423	.000
	Within Groups	79.755	153	.521		
	Total	91.363	156			
Innovation Implementation Status	Between Groups	8.205	3	2.735	3.210	.025
	Within Groups	130.369	153	.852		
	Total	138.573	156			

Abbreviations used: df- degrees of freedom, F- statistic, Sig- Significance level

Table 4. Multivariate Test.

Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's Trace	1.000	173198.671[b]	2.000	11.000	.000
	Wilks' Lambda	.000	173198.671[b]	2.000	11.000	.000
	Hotelling's Trace	31490.667	173198.671[b]	2.000	11.000	.000
	Roy's Largest Root	31490.667	173198.671[b]	2.000	11.000	.000
Aggregate_score_various_innovations	Pillai's Trace	1.960	5.398	220.000	24.000	.000
	Wilks' Lambda	.000	5.232[b]	220.000	22.000	.000
	Hotelling's Trace	110.642	5.029	220.000	20.000	.000
	Roy's Largest Root	73.453	8.013[c]	110.000	12.000	.000
Individual_Innovation_Variables	Pillai's Trace	1.870	12.373	28.000	24.000	.000
	Wilks' Lambda	.003	13.827[b]	28.000	22.000	.000
	Hotelling's Trace	42.820	15.293	28.000	20.000	.000
	Roy's Largest Root	33.912	29.067[c]	14.000	12.000	.000
Aggregate_score_various_innovations * Individual_Innovation_Variables	Pillai's Trace	1.723	3.931	38.000	24.000	.000
	Wilks' Lambda	.018	3.713[b]	38.000	22.000	.001
	Hotelling's Trace	13.218	3.478	38.000	20.000	.002
	Roy's Largest Root	8.319	5.254[c]	19.000	12.000	.003

a. Design: Intercept + Aggregate_score_various_innovations + Individual_Innovation_Variables + Aggregate_score_various_innovations * Individual_Innovation_Variables

b. Exact statistic

c. The statistic is an upper bound on F that yields a lower bound on the significance level

Abbreviations used: df- degrees of freedom, F- statistic, Sig- Significance level

innovation-driven pastoral development. Three imperatives emerge with urgency. This integrated approach is visualised in Fig 4, which bridges historical resilience, contemporary challenges, and innovation gaps. First, innovations must be regionally sequenced, prioritising mobile clinics and hydroponics in climate-vulnerable zones before introducing value-addition in market-proximate areas. Second, pastoralist-led cooperatives should govern implementation to align with cultural protocols, as demonstrated by successful models reducing adoption barriers by 40% (Mehrotra, 2025). Third, policy must formally recognise pastoralists as dryland custodians, embedding innovation bundles into national agricultural frameworks. Future research should prioritise quantifying blockchain applications for direct market access and assessing gendered dimensions of technology adoption. By bridging entrepreneurial adaptation with traditional ecological knowledge, this integrated approach transforms camel pastoralism from a declining practice into a resilient socio-economic lifeline for India's drylands.

Table 5. Tests of Between Subjects Effects.

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	Pastoralist Income	19.102a	144	.133	14.542	.000
	Market Access	23.787b	144	.165	5.255	.001
Intercept	Pastoralist Income	1731.402	1	1731.402	189799.128	.000
	Market Access	1696.073	1	1696.073	53959.124	.000
Aggregate_score_various_innovations	Pastoralist Income	6.580	110	.060	6.557	.000
	Market Access	14.906	110	.136	4.311	.004
Individual_Innovation_Variables	Pastoralist Income	2.984	14	.213	23.369	.000
	Market Access	3.560	14	.254	8.090	.000
Aggregate_score_various_innovations * Individual_Innovation_Variables	Pastoralist Income	.720	19	.038	4.152	.008
	Market Access	2.043	19	.108	3.422	.017
Error	Pastoralist Income	.109	12	.009		
	Market Access	.377	12	.031		
Total	Pastoralist Income	2095.581	157			
	Market Access	2058.748	157			
Corrected Total	Pastoralist Income	19.212	156			
	Market Access	24.164	156			

a. R Squared = .994 (Adjusted R Squared = .926)
b. R Squared = .984 (Adjusted R Squared = .797)

Table 6. Regression Model Summary.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.812[a]	.659	.655	.39747

a. Predictors: (Constant), Market Volatility Indicators, Innovations Implementation.

ANOVA[a]						
Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	47.033	2	23.516	148.856	.000[b]
	Residual	24.329	154	.158		
	Total	71.362	156			

a. Dependent Variable: Resilience Indicators (Camel Health, Productivity, Income Stability)
b. Predictors: (Constant), Market Volatility Indicators, Innovations Implementation

Coefficients[a]						
Model	Unstandardised Coefficients		Standardised Coefficients		t	Sig.
	B	Std. Error	Beta			
1	(Constant)	.883	.187		4.727	.000
	Innovations Implementation	1.732	.307	1.768	5.646	.000
	Market Volatility Indicators	2.489	.310	2.515	8.032	.000

a. Dependent Variable: Resilience Indicators (Camel Health, Productivity, Income Stability)

Findings of Study

This study provides empirical evidence that entrepreneurial innovations are fundamentally reshaping the economic sustainability of camel pastoralism across India's arid and semi-arid regions, particularly in Rajasthan, Gujarat, and Haryana, where livelihoods and cultural identities remain closely tied to camel herding traditions (Dumont, 2023; Blench, 2023). Over the past three decades, the camel population has plummeted by more than 75%, including a sharp 37% drop since 2012 (Sharma *et al,* 2020). The analysis shows that mobile veterinary clinics significantly reduce climate-induced herd mortality by 25% ($F = 7.251$, $p < 0.001$), reinforcing prior findings from Rajasthan (Gurbir *et al,* 2020) and Kenya (Omondi *et al,* 2021), where

similar interventions achieved even higher disease reduction rates. These clinics offer crucial health services including vaccinations and diagnostics that mitigate the growing stressors of drought, heat, and forage scarcity, which have collectively undermined camel immunity by as much as 45% in some regions (Farooq *et al,* 2023; Al Jassim and Sejian, 2015). At the same time, hydroponic fodder systems are addressing chronic feed shortages by producing nutrient-dense forage with 90% less water than conventional methods (Orina *et al,* 2024), providing consistent nutrition even as pasturelands in Rajasthan have shrunk by 22% since 2000 (Banerjee *et al,* 2023). Statistically, these systems are strongly linked to improved herd productivity and economic output ($F = 9.306$, $p < 0.001$), aligning with similar agro-technological interventions seen in East Africa. In parallel, value-added processing of camel milk such as probiotic drinks and artisanal dairy products has led to a 35% increase in pastoralist income ($F = 7.423$, $p < 0.001$) by enabling access to urban and premium markets, while also reducing reliance on middlemen who historically captured up to two-thirds of the product's market value (Faye and Corniaux, 2024). Importantly, the combined deployment of these three innovations produces a synergistic effect: pastoralists who adopt all three experience a 50% increase in market access (Pillai's Trace = 1.960, $p < 0.001$), due to the way animal health, reliable fodder supply, and value-chain participation reinforce each other. Climate resilience is especially enhanced when veterinary care and hydroponics are implemented together ($\beta = -1.768$, $p < 0.001$), while value addition enables producers to treat price fluctuations not as threats but as opportunities, echoing the flexible strategies found in Somali leasing systems (Decker *et al,* 2025) and Indian dairy cooperatives (Volpato and King, 2019), where income is strategically timed to market cycles ($\beta = 2.515$, $p < 0.001$). Taken together, these findings highlight the inadequacy of fragmented or one-dimensional interventions. Instead, the integrated "innovation triad" comprising healthcare, sustainable feed, and market-oriented production constructs a resilient pastoral economy grounded in both entrepreneurial adaptation and traditional ecological knowledge. This model offers a replicable pathway for safeguarding camel-based livelihoods and the broader 3,000-year legacy of pastoralism amid accelerating climate and economic pressures, operationalizing the "embodied landscapes" of pastoral wisdom described by Ohte *et al* (2025).

Conclusion and Policy Recommendation

This study underscores the vital role of entrepreneurial innovations in enhancing the economic sustainability of camel pastoralism amid evolving climate and market challenges. Innovations such as mobile veterinary clinics, hydroponic fodder systems, and value-added camel milk products improve herd health, feed efficiency, and market opportunities, while water-efficient agro-ecological practices significantly reduce resource use. The integration of these modern technologies with traditional pastoral practices offers a balanced approach that preserves both cultural heritage and the ecological landscapes of communities like the Raika and Maldhari.

To ensure long-term resilience and growth, policies should promote the bundled deployment of these innovations across key regions, support the formation of pastoralist-led cooperatives, and develop climate-adaptive logistics such as solar-powered cold chains for value-added products. Equally critical is the formal recognition of pastoralists as custodians of dryland resilience within national agricultural frameworks. Ultimately, the strategic adoption and institutional support of such entrepreneurial innovations are essential for securing the future of camel pastoralism in an increasingly unpredictable environment.

Implications and Future Research

The findings of this study underscore the necessity of a comprehensive approach to enhancing pastoralist livelihoods through entrepreneurial innovations. The integration of mobile veterinary clinics, hydroponic fodder systems, and value added camel milk products reveals the importance of a multi-faceted strategy tailored to address the specific challenges faced by camel pastoralists. Future research should focus on understanding the mechanisms through which these innovations impact pastoralist livelihoods, exploring their long term effects, and evaluating their economic viability. Additionally, assessing regional and cultural factors that may influence the effectiveness of these innovations will be crucial. Investigating the role of policy interventions in promoting the adoption and scaling of these innovations will provide valuable insights for sustainable development and improved support for pastoralist communities.

Conflict of Interest

The authors confirms there is no conflict of interest.

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