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Sheep production systems in Salinas, San Luis Potosí: characterization and challenges for their sustainability in semi-arid regions of Mexico



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Abstract

This study characterized sheep production systems in Salinas, San Luis Potosí, Mexico, based on structured surveys applied to 40 producers sampled through non-probabilistic snowballing. Sociodemographic, productive, sanitary, environmental, and marketing aspects were recorded, as well as their relationship with producers' perception of drought impact. Data were analyzed using descriptive statistics, associations between categorical variables were evaluated with chi-square tests, and monotonic associations involving ordinal variables were assessed using Spearman rank correlations. Producer typologies were identified using Gower distance and k-medoids clustering (PAM), with the number of clusters selected by silhouette width. Results showed predominance of mixed grazing-partial confinement management (75%), rustic pens (97.5%), limited supplementation and preventive health practices (15% reported regular vaccination). Drought was perceived as "very severe" by 77.5% of producers, and reported losses averaged 6.9 animals per production unit (maximum 40). Correlation analyses indicated weak, non-significant associations between drought perception, losses and producer age. Clustering identified two producer profiles largely differentiated by management: mixed systems (n= 30), with larger flocks and higher reported losses, and intensive systems (n= 10), with smaller flocks and lower reported losses. These findings support the need for differentiated interventions focused on low-cost feeding and health management, drought preparedness and market strengthening for semi-arid sheep systems.

Keywords: Sheep production; Traditional systems; Drought; Climate resilience; Rural producers

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Introduction

Sheep production is a key livelihood activity in arid and semi-arid regions because it can convert low-quality forage resources into marketable products, primarily meat, and in some contexts wool and milk, supporting household income and local food supply. In Mexico, sheep farming is commonly integrated into smallholder and mixed crop-livestock systems, where producers must cope with limited water availability, seasonal forage shortages, and restricted access to capital and technical services^{1,2}.

In the Potosino Plateau, particularly in the municipality of Salinas, San Luis Potosí (SLP), sheep production has a long tradition but operates under increasingly restrictive environmental conditions. Low and erratic rainfall, rangeland degradation, and soil limitations have historically favored extensive, low-input management, often with minimal infrastructure and limited adoption of innovations. These constraints, together with pressures associated with overgrazing and advancing desertification, can reduce forage availability and quality, thereby limiting productivity and increasing exposure to drought-related losses^{3,4}.

Evidence from other semi-arid regions indicates that improving sheep systems requires more than technical recommendations; it depends on understanding how producers' socioeconomic characteristics, management decisions, and resource endowments shape vulnerability and adaptive capacity to climatic stressors such as drought^{5,6}. However, for Salinas (SLP), the available information is fragmented and does not adequately integrate the structural features of production units (e.g., herd size and resources), the organization and technical capacities of producers, and key constraints related to feeding, health management, and marketing. This knowledge gap restricts the design of feasible, context-specific strategies that differentiate interventions according to the realities of distinct producer groups.

A typological characterization of sheep production systems can help identify producer profiles, describe common management patterns, and prioritize targeted actions aligned with local constraints and opportunities. Recent evidence in Mexico highlights the value of multivariate approaches to classify livestock production systems and support differentiated interventions and policy design⁷. This perspective is particularly relevant in semi-arid territories, where sustainability depends on both, productive efficiency and the responsible use of rangeland and feed resources.

Therefore, the objective of this study was to characterize sheep production systems in Salinas, SLP, Mexico, using socioeconomic, technical, environmental, and commercial indicators, and to identify producer profiles that can inform strategies to improve efficiency and sustainability in the region. It was hypothesized that (i) sheep production in Salinas can be classified into distinct producer profiles based on structural and management attributes, and (ii) these profiles differ in their perceived constraints and adaptive capacity to drought, which has direct implications for prioritizing interventions.

Material and methods

Study area

The study was conducted from November 2024 to February 2025 in the municipality of Salinas, located in the Potosino Plateau region of San Luis Potosí (SLP), Mexico. This area has an elevation between 1,900 and 2,800 m asl and is situated between 23°11' and 22°27' N and 101°22' and 101°57' W⁸. The dominant climate is temperate dry (BS1kw), covering 74.74 % of the territory, and temperate semi-dry,

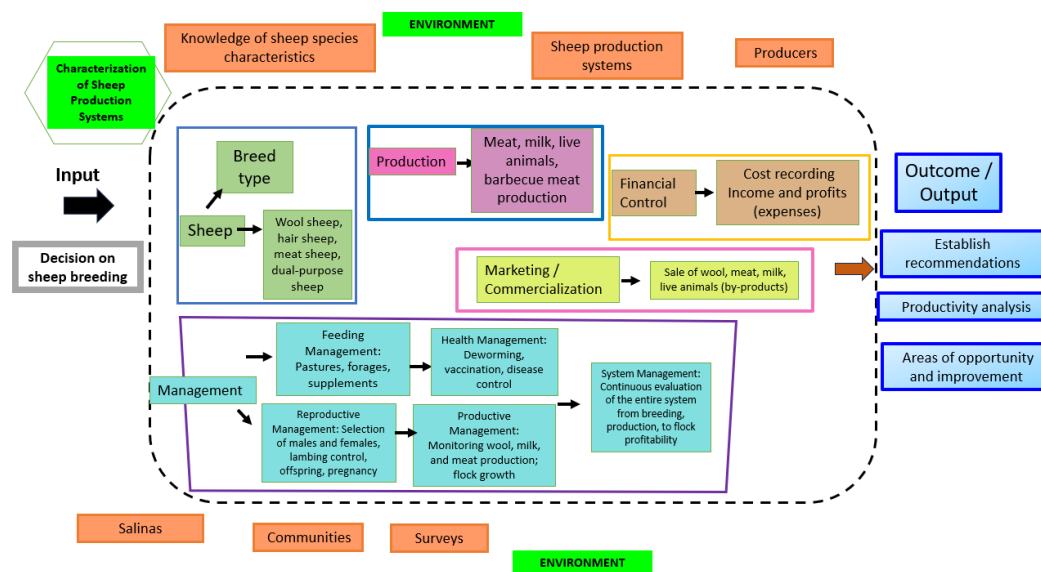
covering 25.26 %, with an average annual temperature of 14 to 18 °C and yearly rainfall ranging from 300 to 500 mm⁹.

According to official records, Salinas has approximately 1,091 sheep production units and 20,941 heads, indicating that sheep husbandry represents a relevant activity within the municipality¹⁰. Fieldwork focused on seven communities with active sheep-raising activity: San Juan sin Agua, El Alegre, Santa María, Jacalón, San Antonio de la Paz, Colonia Zaragoza, and San Tadeo. These communities were selected to capture the municipality's main sheep-producing areas and the diversity of management conditions encountered in the region.

Comprehensive diagnosis of the sheep production system

A structural framework was used to guide the characterization of sheep production systems and to ensure consistent data capture across producers. [Figure 1](#) summarizes the main components of the regional sheep system, from producers' resource endowment and management decisions (feeding, reproduction, health, and basic recordkeeping) to output destination and commercialization. The diagram was used as an organizing tool to identify potential bottlenecks and to align the questionnaire with the production process under semi-arid conditions.

Figure 1. Flow diagram for the characterization of sheep production systems in Salinas, S.L.P., Mexico



Methodological design, sampling, and data collection

A total of 40 structured interviews were conducted with sheep producers. Because no complete sampling frame was available and producers are spatially dispersed, a non-probabilistic snowball sampling approach was used, which is common in rural research when participant identification relies on local networks¹¹. Initial participants were identified through local contacts and subsequently referred additional active producers in the same or nearby communities. Field access was further constrained by producers' limited availability during the day due to livestock-related workloads and herd mobility, as many producers were actively grazing or herding their animals at the time of visits. Therefore, interviews often required flexible scheduling and, in some cases, repeated visits to complete data collection. Interviews were conducted *in situ* at the production unit or at nearby grazing areas, depending on producers' daily routines.

The sample size ($n = 40$) was defined based on field feasibility, coverage of the main sheep-producing communities, and information saturation, i.e., the point at which additional interviews no longer contributed substantially new combinations of management practices, constraints, or marketing pathways within the study area.

The questionnaire was designed with a multidimensional approach and adapted to the local context. It included sections to gather information on sociocultural aspects, such as age, gender, educational level, and the number of family members involved in production; productive aspects, such as breed, flock size and management, use of supplements, and type of feeding; health aspects, related to vaccine and medication administration, infrastructure type, and veterinary care frequency; and environmental aspects, like management type (free grazing, semi-confinement, or confinement), pasture condition, and perceived drought impact. Economic and market variables were also included, such as production destination (live animal sales, wool), marketing channels, and income generation frequency^{12,13}. Additionally, direct observation was used as a complementary technique to validate responses, document management system conditions, assess herd health, and record productive infrastructure features, thereby enhancing the reliability of the collected data¹¹.

Statistical analysis

Data were processed in Python (v3.11). A descriptive and exploratory inferential approach was applied. Quantitative variables were summarized using measures of central tendency and dispersion, and categorical variables were summarized using absolute and relative frequencies.

Associations between categorical variables: Chi-square tests of independence were used when expected cell counts met assumptions; otherwise, exact tests were applied as appropriate.

Associations involving ordinal variables: Because some variables (e.g., perceived drought impact) are ordinal, Spearman's rank correlation (ρ) was used to evaluate monotonic associations with quantitative variables (e.g., producer age and reported drought-related deaths). Correlation coefficients were interpreted conservatively, emphasizing that small values represent weak associations and should not be used as stand-alone evidence for strong effects.

Producer profiles (typology): To identify producer profiles using mixed data types (numeric, ordinal, and categorical), a clustering approach suitable for mixed variables was implemented. First, pairwise dissimilarities were computed using Gower distance. Producer typologies were then obtained using partitioning around medoids (PAM; k-medoids)¹⁴. The optimal number of clusters was determined based on internal validity criteria, primarily average silhouette width, and interpretability within the context of local production conditions.

Cluster solutions were described by comparing variables across groups using appropriate tests (e.g., Kruskal-Wallis or ANOVA for quantitative variables depending on distributional assumptions, and Chi-square or Fisher's exact tests for categorical variables). When graphical representation was needed, dimensionality reduction was used only for visualization purposes and was not interpreted as evidence of latent constructs.

Results and discussion

Sociodemographic characteristics of producers

The analysis of sociodemographic data showed that sheep producers in the municipality of Salinas, SLP, Mexico, have an average age of 48.9 yr (SD= 15.6), ranging from 21 to 80 yr. This age diversity indicates the presence of both young and older producers, indicating the coexistence of younger and older decision-makers within local sheep farming. Similar studies in semi-arid regions of northern Mexico

have emphasized that aging of primary decision-makers can constrain technology adoption and long-term continuity of livestock activities unless younger generations engage in decision-making and management^{4,15}.

Regarding gender, 65 % of respondents were men and 35 % were women. While sheep production is often reported as male-dominated in many rural settings, women's participation in management and household-level production decisions has been increasingly documented in smallholder systems, particularly where out-migration or off-farm employment of men redistributes labor and decision responsibilities^{16,17}. In this context, the observed female participation is relevant for designing technical assistance and training programs that explicitly consider women as direct beneficiaries and active agents within production units.

Educational attainment was generally low: 50 % of producers reported primary education, 35 % secondary education, 7.5 % upper secondary or higher education, and 7.5 % no formal schooling. Low schooling levels can limit access to information, administrative processes for public support programs, and consistent recordkeeping, which are often prerequisites for the adoption of improved management practices. Recent work in small ruminant systems has highlighted that, beyond formal education, practical training and extension models adapted to local conditions can partially compensate for low schooling, particularly when supported by simple tools for animal health, feeding planning, and marketing^{5,6,18}.

Finally, respondents reported an average of 2.5 economic dependents per production unit, underscoring the role of sheep farming as part of household livelihood strategies. In semi-arid, resource-limited territories, the dependence burden may influence risk tolerance and reinvestment capacity, affecting decisions related to supplementation, preventive health practices, and infrastructure improvements¹. Overall, these sociodemographic patterns suggest heterogeneous capabilities and constraints among producers, reinforcing the need to tailor interventions according to producer profiles rather than applying uniform recommendations.

Productive, nutritional, and flock management characteristics

The average flock size was 23.8 animals (SD= 16.7), with reported values ranging from 1 to 53 heads per producer. This distribution reflects a continuum from very small "backyard" flocks to small-scale units, in which sheep husbandry functions as a complementary activity within broader household livelihood and mixed farming strategies. The high variability in flock size suggests unequal access to key resources (e.g., grazing availability, cash flow for feed purchase, and labor), which has also been reported for sheep systems in semi-arid regions of Mexico^{4,15,19}. From a sustainability perspective, small flock sizes can limit economies of scale and reduce capacity to absorb climatic or market shocks, but may also reflect risk management strategies under uncertain forage availability.

With respect to management, 75 % of producers reported mixed practices (grazing combined with partial confinement), while 25 % reported intensive management. Mixed systems are often a functional response to seasonality, allowing producers to rely on rangelands when forage is available and shift to confinement and supplementation during drought or forage scarcity. Nevertheless, the productive benefits of this strategy depend on the quality of feeding planning, health management, and infrastructure adequacy; without technical planning, mixed systems may reduce immediate risk without necessarily improving productivity indicators⁶.

Flocks were primarily composed of Dorper and Rambouillet sheep, including Dorper × Rambouillet crosses, consistent with a meat-oriented production objective with a secondary wool component. Infrastructure was predominantly rudimentary: 97.5 % of producers used rustic pens constructed with low-cost materials (e.g., branches, stones, recycled wire mesh), and only 2.5 % reported permanent or

technically improved facilities. Limited infrastructure can constrain basic biosecurity measures (e.g., isolation of sick animals), hygiene practices, and controlled feeding, all of which can influence animal welfare and health outcomes. Similar constraints have been identified as structural bottlenecks in traditional small ruminant systems, particularly under semi-arid conditions where disease prevention and stress mitigation are critical^{15,19}.

Feeding practices relied primarily on grazing and crop residues, with limited supplementation. Only 12.5 % reported using mineral supplements, 30 % used coarse salt, and 7.5 % reported providing targeted supplementation to dams. Starter feeds and fattening rations were rarely used. While these practices may reflect rational choices under economic constraints, limited supplementation can reduce growth rates, reproductive performance, and resilience to disease and heat/forage stress, especially during drought periods^{1,5}. Together, these production and management attributes support the identification of producer profiles based on multiple structural and decision-related variables (e.g., management type, flock size, and resource endowment), rather than age alone.

Health conditions of the production systems

Sanitary management in the surveyed sheep production units in Salinas (SLP) showed limited adoption of preventive practices and low access to veterinary support. Only 15 % of producers reported regular vaccination, whereas 85 % indicated that they did not follow a consistent vaccination schedule. This pattern may reflect multiple constraints, including limited availability of veterinary services, costs, and gaps in technical guidance for smallholders in semi-arid settings^{3,5}.

Producers reported respiratory signs as the most frequent health problem (47.5 %), while mastitis (5 %) and abortions (10 %) were less commonly reported. Importantly, 40 % of respondents indicated that they did not know the specific causes of health problems in their flocks. Limited diagnostic capacity, together with symptom-based management and limited recordkeeping capacity, can potentially delay timely control measures, especially where preventive programs are not routinely implemented.

Infrastructure conditions were also restrictive for basic biosecurity. Most producers (97.5 %) kept animals in rustic pens made from low-cost, improvised materials, and only one producer (2.5 %) reported permanent facilities. Under such conditions, the consistent implementation of simple measures (e.g., isolation of sick animals, routine cleaning and disinfection, controlled entry of replacement animals, and organized manure handling) becomes difficult, which can indirectly affect animal health and welfare outcomes^{4,15}.

Overall, these results suggest that improving flock health in Salinas will require interventions that combine (i) feasible preventive packages (vaccination/deworming calendars and basic biosecurity routines), (ii) locally adapted training, and (iii) low-cost infrastructure upgrades. Beyond productivity, strengthening sanitary management may also improve system resilience under drought and market constraints, and it may facilitate access to support programs and formal marketing channels that require minimum health standards or documentation. These actions are likely to be most effective when tailored to producer profiles that differ in resource endowment and management intensity.

Environmental conditions and vulnerability to drought

Sheep production in Salinas operates under a dry temperate climate with annual rainfall commonly below 500 mm. In this context, management strategies are strongly shaped by forage seasonality and rangeland condition. Most producers reported using mixed management (grazing combined with partial confinement; 75 %), while 25 % reported intensive management. This distribution may indicate a tendency toward partial confinement as a practical response to forage scarcity and rangeland degradation; however, the effectiveness of this shift depends on access to feed, water, and planning

capacity^{4,6}. Such constraints may affect producer profiles differently, particularly when management intensity and resource availability vary across systems.

Perceived drought impacts were high: 77.5% of producers classified drought effects as “very severe”. The most frequently reported consequences were reduced forage production (70 %) and the need to purchase external feed (60 %). Reported drought-related losses averaged 6.9 animals per production unit, with extreme cases reaching 40 heads. These losses correspond to the year before the survey, as reported by producers. While these figures are self-reported, they align with the pattern described for arid and semi-arid systems where recurrent drought increases feeding costs, mortality risk, and pressure on household income^{3,15}. These patterns are consistent with broader evidence showing that climate variability and drought intensify feed constraints and economic stress in livestock systems, increasing vulnerability and compromising sustainability²⁰.

To contextualize environmental conditions during the study period, institutional weather-station records from the Colegio de Postgraduados (Campus San Luis Potosí, Salinas) indicated an accumulated rainfall of 143 mm in the 12 mo prior to field data collection, substantially below the typical annual range reported for the municipality. This rainfall deficit provides a plausible climatic background for producers' perceptions and reported losses.

Despite some efforts to intensify management during critical months, adaptive capacity appears constrained by limited forage reserves, restricted access to supplementation strategies, and scarce water resources. Continued rangeland deterioration and low vegetation cover may further reduce rangeland recovery and exacerbate desertification processes, increasing long-term vulnerability^{1,5}. In this setting, priority options include forage conservation (e.g., hay, crop-residue management), strategic supplementation, and water and soil conservation practices; additionally, diversifying drought-resilient feed resources (e.g., integrative use of C4 grasses and forage shrubs) may help stabilize forage supply in Mexican drylands²¹.

Economic and commercial aspects of the sheep production system

The results indicate that sheep production in Salinas is predominantly oriented toward the sale of live animals, reported by 92.5 % of producers. This marketing strategy appears to be driven by its operational simplicity, immediate liquidity, and direct access to local buyers. However, reliance on the sale of unprocessed animals generally reduces producers' ability to capture added value along the value chain and may increase exposure to seasonal price variability⁴.

Although 52.5 % of producers reported obtaining wool as a by-product, only 42.5 % reported being able to sell it, suggesting structural constraints in the local wool market. Reported barriers commonly include low demand, limited storage capacity, and buyers' requirements for sorting and quality attributes (e.g., cleanliness, separation by color), which can discourage commercialization. This pattern is consistent with broader trends in several sheep-producing regions where traditional wool markets have contracted due to competition with synthetic fibers and shifting consumer preferences^{5,6}. Given that flocks include Rambouillet and Dorper × Rambouillet crosses, wool production exists as a secondary output; however, commercialization remains constrained by market and quality requirements.

None of the surveyed producers reported milk production, reinforcing the meat-oriented profile of the local system. This likely reflects breed composition (predominantly Dorper and Rambouillet crosses), limited infrastructure for milking and processing, and the absence of established dairy marketing channels. While sheep dairy products can represent a diversification pathway in other contexts, their feasibility in Salinas should be considered a medium-term option contingent on clear prerequisites (breed suitability, hygiene infrastructure, training, and market access), rather than an immediate recommendation¹⁶.

Marketing channels were predominantly informal, relying on personal networks and direct sales, with limited participation in producer organizations or collective marketing schemes [Table 1](#). This can constrain bargaining power and reduce access to higher-value or institutional markets. Together, these findings suggest that interventions to strengthen profitability should prioritize feasible, context-specific actions such as improving market information, promoting basic quality and handling practices, and exploring forms of producer coordination that reduce transaction costs and improve price negotiation. Value-adding options (e.g., improved carcass quality and targeted marketing, simple wool handling standards, or small-scale processing where feasible) should be evaluated through a practicality lens, including costs, technical requirements, and local demand.

Table 1. Multidimensional overview of sheep production systems in Salinas, San Luis Potosí, Mexico

Evaluated dimension	Indicator	Observed result
Sociocultural	Producer age	48.9 yr (SD=15.6; range: 21-80)
	Gender distribution	65 % men, 35 % women
	Education level	Primary (50 %); secondary (35 %); upper secondary/higher (7.5 %); no formal education (7.5 %)
	Economic dependents	2.5 individuals on average
Productive	Flock size	23.8 animals (SD=16.7)
	Predominant management	Mixed (grazing + partial confinement): 75 %; intensive: 25 %
	Breed composition	Dorper, Rambouillet, and Dorper × Rambouillet crosses
	Housing/corral type	Rustic pens: 97.5 %; improved/permanent facilities: 2.5 %
	Supplementation	Limited; mineral supplements: 12.5 %; coarse salt: 30 %; targeted supplementation to dams: 7.5 %
Health	Systematic vaccination	15 % report regular vaccination
	Most frequent health problems (reported)	Respiratory signs (47.5 %), abortions (10 %); mastitis (5 %)
	Biosecurity-related infrastructure	Limited; facilities mostly rustic (97.5 %)
Environmental	Management type	75 % mixed, 25 % intensive
	Perceived drought severity	"very severe" 77.5 %
	Reported drought effects	Reduced forage availability/production: 70%; increased purchase of external feed: 60 %
	Reported drought-related losses	Mean: 6.9 animals per unit; maximum: 40
Economic/ Commercial	Main product marketed	Live animals: 92.5 % sell live animals
	Wool commercialization	52.5 % obtain wool; 42.5 % report selling wool
	Milk production	0 % reported milk production
	Marketing channels	Predominantly direct and informal sales

Associations between sociodemographic, climatic, and productive variables

Exploratory association analyses showed weak relationships between reported drought-related losses and climate perception variables. The association between drought-related mortality losses and perceived drought damage was weak (Spearman's $P \approx 0.06$), and the association between perceived damage and overall drought impact was also weak ($P \approx 0.06$). Similarly, producer age showed weak associations with climate perception variables ($P \approx 0.16$ for overall drought impact and $P \approx 0.06$ for perceived damage). None of these associations were significant ($P > 0.05$).

Overall, these results suggest that producers' perceptions of drought impacts are not strongly explained by age or reported losses in this sample. Therefore, correlation analyses should be interpreted cautiously

and used only as exploratory evidence, rather than as a basis for causal interpretations. This reinforces the value of complementary approaches, such as typology analyses based on multiple structural and management variables, to better understand heterogeneity in vulnerability and adaptive capacity among sheep producers in semi-arid systems^{3,4}.

Contingency tables: type of management and perceived drought severity

The contingency table suggests a descriptive difference in perceived drought severity across management types. Among producers using mixed management, 83.3 % (25/30) classified drought as “very severe,” compared with 60.0 % (6/10) of producers under intensive management. However, because some expected cell counts were below 5, Fisher’s exact test was used, and the association was not statistically significant ($P=0.190$). Therefore, the observed difference should be interpreted as a non-conclusive trend rather than evidence of a robust association.

Overall, the high proportion of “very severe” responses across both systems highlights drought as a major constraint regardless of management strategy. Although not statistically significant, this pattern may still help guide future work aimed at evaluating whether management intensity and resource availability influence perceived vulnerability under drought conditions^{4,5}.

Producer typology (Gower distance + PAM)

Producer profiles were identified using a clustering approach suitable for mixed data types (numeric, ordinal, and categorical). Pairwise dissimilarities were computed using Gower distance, and producers were grouped using partitioning around medoids (PAM; k-medoids). The clustering was performed using a set of structural and management variables (including management type, flock size, reported drought-related losses, perceived drought severity, and key sociodemographic indicators). Based on internal validity (average silhouette width) and interpretability, a two-cluster solution ($k= 2$) provided the best fit for the data.

Overall, the typology separated producers primarily by management intensity, which also aligned with differences in reported drought-related losses and flock size:

Profile 1 (Mixed management; $n= 30$): Producers operating grazing combined with partial confinement. This profile tended to have larger flocks and higher reported drought-related losses, consistent with greater exposure to forage variability and the need for seasonal feed adjustments.

Profile 2 (Intensive management; $n= 10$): Producers reporting more intensive management practices. This profile tended to have smaller flocks and lower reported drought-related losses, which may reflect greater control over feeding and housing conditions during critical months.

This typology provides a practical framework for differentiated recommendations. For mixed-management producers, priority actions may include low-cost forage conservation and strategic supplementation to reduce drought-related mortality. For more intensive producers, interventions may focus on strengthening preventive health routines and improving market strategies, while maintaining cost-efficiency. These profiles are descriptive and should not be interpreted as causal categories.

Integrated analysis of results and implications for sheep farming sustainability

This study provides an integrated characterization of sheep production systems in Salinas, S.L.P., highlighting structural constraints that limit sustainability under high climate vulnerability. Sociodemographically, producers were predominantly middle-aged, with low formal education and strong family dependence on livestock-related income, a pattern consistent with small ruminant systems in semi-arid regions of Mexico^{4,5,22}. These conditions can reduce access to technical

information, limit recordkeeping, and constrain participation in support programs that require basic documentation.

From a production standpoint, mixed management (grazing combined with partial confinement) predominated, flock sizes were generally small, and investment in supplementation, preventive health practices, and infrastructure was limited. The low frequency of regular vaccination and the predominance of rustic housing conditions suggest that feasible preventive packages and low-cost facility improvements remain priority entry points for technical assistance^{5,16}. Economically, the system is primarily oriented toward live-animal sales, while wool represents a secondary output with limited commercialization. Milk production was not reported, indicating that diversification into dairy should be considered only as a medium-term option contingent on clear prerequisites (breed suitability, hygiene infrastructure, training, and market access)¹⁶.

Drought emerged as a dominant constraint: most producers perceived its effects as "very severe," and reported drought-related mortality losses were substantial. However, exploratory association analyses indicated that correlations between reported losses, drought perceptions, and age were weak and not statistically significant, reinforcing those simple bivariate relationships are insufficient to explain heterogeneity in vulnerability and responses. Similarly, the difference in perceived drought severity between management types did not reach statistical significance (Fisher's exact test, $P=0.190$), suggesting that high perceived drought pressure is widespread across systems.

To better capture heterogeneity, a typology based on mixed-variable clustering (Gower distance + PAM) identified two producer profiles primarily differentiated by management intensity (mixed vs intensive), with consistent differences in flock size and reported drought-related losses. This typology supports targeted recommendations: for mixed-management producers, priorities include low-cost forage conservation, strategic supplementation, and basic drought preparedness to reduce mortality during critical periods; for more intensive producers, interventions may emphasize preventive health routines, efficiency of feeding strategies, and market-oriented practices to improve profitability while controlling costs. Overall, strengthening locally adapted extension, facilitating producer coordination, and integrating women and younger family members as direct recipients of training and support may improve the resilience of sheep farming systems in semi-arid territories^{23,24}.

Conclusions and implications

Sheep production systems in Salinas, San Luis Potosí, Mexico, face significant climatic and structural challenges, including low technological adoption, mostly mixed management (grazing with some confinement), rustic infrastructure, and limited investment in supplementation and preventive healthcare, all of which limit productivity and increase vulnerability. Drought is consistently seen as the biggest stressor and is linked to heavy animal losses and greater economic instability. Under these conditions, the most immediate and cost-effective measures are strengthening preventive health routines (vaccination and deworming schedules, basic hygiene, and biosecurity) and making simple facility improvements. Production mainly focuses on live-animal sales; wool is a secondary product with marketing challenges, so adding value or diversifying should only be considered once basic requirements like training, infrastructure, and market access are met. The differences among producers indicate different management styles, highlighting the need for tailored recommendations based on the level of intensification. Overall, sustainability can be enhanced through integrated, context-specific actions that prioritize forage preservation and strategic supplementation to lower drought-related deaths, along with improving producer coordination to boost marketing and bargaining power.

Acknowledgments and conflict of interest

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