Agricultura, Sociedad y Desarrollo

TERRITORIAL RESILIENCE: ARTICULATING RESOURCES, SOCIAL CAPITAL AND ADAPTABILITY IN LIVESTOCK MICROENTERPRISES IN TANTOYUCA, VERACRUZ

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Citation: Sánchez-Galván F, Bautista-Santos H, Hermosilla-Zavala J, Ireta-Paredes AR, Rodríguez-Zuñiga J. 2026. Territorial resilience: articulating resources, social capital and adaptability in livestock microenterprises in Tantoyuca, Veracruz. Agricultura, Sociedad y Desarrollo https://doi.org/10.22231/asyd.v23i1.1769

ASyD(23): 75-95

Editor in Chief:
Dr. Benito Ramírez Valverde

Received: March 28, 2025.
Approved: July 10, 2025.

Estimated publication date:
January 2, 2026.

ABSTRACT

This research analyzed the adaptation mechanisms of a small livestock enterprise, specializing in the fattening of semi-penned cattle in the face of disruptions caused by COVID-19. It revealed a conceptual framework for territorial resilience based on three interconnected support mechanisms. Three production cycles (pre-pandemic, pandemic, and post-pandemic) were studied, applying a longitudinal design that combined semi-structured interviews, direct observation, and quantitative analysis of production costs. A hierarchical model was used to analyze the supply chain, examining production efficiencies and strategic adaptations. Results indicated that resilience was based on three support mechanisms: (1) local resources (38 ha, 3 water holes), which reduced dependence on external inputs by 27%, (2) relational assets, community networks (trust networks with 68% of recurring customers) and (3) adaptive capacity that prioritized local exchange circuits (92% of sales ≤50 km). This network made it possible to maintain 100% operability and ensure a rapid recovery with profit margins that went from 11% during the crisis to 21.2% in the post-pandemic phase. Among the adaptive innovations based on tacit knowledge, the temporary substitution of balanced feed with orange peel and the autonomous production of corn silage stand out. The study provides a conceptual framework for understanding resilience in disruptive contexts, not as an intrinsic attribute of geographic space, but as the result of active strategies that link local scales with external markets. It highlights the importance of operational flexibility and networks of trust for the sustainability of rural microenterprises.

Keywords: adaptive capacity, local exchange circuits, relational assets, socio-territorial assets.

INTRODUCTION

Cattle farming in Mexico combines production systems that include both highly technological systems and economies that are of traditional type (Ministry of Agriculture, Livestock, Rural Development, Fisheries and Food-SAGARPA, 2018). This heterogeneity is reflected in the fact that of the 34.04 million head of cattle produced in Mexico, 61.7% are produced in free grazing,

15.1% in controlled grazing, 15% in corral or stable, and 8.3% in a combination of corral or stable and grazing (Instituto Nacional de Estadística y Geografía-INEGI, 2019).

According to the Food and Agriculture Organization of the United Nations (FAO), Mexico established itself as one of the top ten global cattle producers during the period 2011-2020, contributing an average of 2.7% of global production, which reached 70 million tons. This prominent international position was led by the United States (17%) and Brazil (13.7%), while China accounted for 8% of global production. Cattle production in Mexico showed a marked regional concentration, with the states of Veracruz, Jalisco, San Luis Potosí, and Chiapas contributing 36% of national production, which totalled 3.5 million tons (Food and Agriculture Organization of the United Nations-FAO, 2022).

Veracruz has proved to be the main national producer, although with average weights per animal (439 kg) are lower than those of northern states, such as Baja California or Jalisco and with a predominant orientation towards the domestic market, as evidenced by its minimal participation in live cattle exports (0.4%), compared to states such as Chihuahua (General Directorate of Agri-Food and Fisheries Information Services-DGSIAP, 2020; National Health Service, Safety and Agri-Food Quality-SENASICA, 2021). The economic importance of this sector in Veracruz is reflected in its contribution of 5.6% to the national agricultural Gross Domestic Product (GDP) and first place nationally in beef production (INEGI, 2019). In 2020, state production reached 268.28 thousand tons of meat from 1.1 million heads (Agrifood Information System (SIACON), 2020). This productive context is part of a unique social structure. Livestock farming in Veracruz is organized under a strict sanitary framework to comply with the international market.

The state is divided into two export regions: region A, which extends from the Papaloapan River to the Pánuco River (165 municipalities), has "modified accredited" status from the United States Department of Agriculture for meat exports; and region B, which extends from the Papaloapan River to Las Choapas (47 municipalities), authorized for national mobilization (SENASICA, 2021). This export infrastructure is supported by a network of 80 slaughterhouses (16 private, 55 municipal, and 9 Federal Inspection Type -TIF-) (State Center for Statistical and Geographic Information-CEIEG, 2019), backed by 50 zoosanitary certification centers and 72 veterinarians authorized to perform epidemiological surveillance tests, such as the caudal fold test (SENASICA, 2021). This regulatory and infrastructure context is essential for understanding the costs and regulatory requirements faced by producers; particularly those seeking access to formal and export markets.

According to information from the National Agricultural Survey (INEGI, 2019), the state of Veracruz accounted for 11.9% of the total number of agricultural producers nationwide and 13.3% of the labor force employed in these activities. This productive model faces the challenge of reconciling the proper management of forest resources and biodiversity with livestock systems, which are characterized by the use of large areas of pasture and the introduction of exotic forage species (Gavito *et al*., 2017). Given this scenario, the occurrence of disruptive events such as the COVID-19 pandemic, which generated widespread logistical disruptions and affected the global food supply chain (Aday and Aday, 2020), obligates these productive systems to develop response capacities that permit them to remain operational.

Under these conditions, territorial resilience is conceived as a dynamic process through which socio-spatial systems—understood as social organization and territorial structure—mobilize local resources and collaborative networks to confront crises (Brunetta *et al*., 2019; Sánchez-Zamora *et al*., 2016). In rural contexts, this is manifested in the ability of livestock units to reorganize their productive systems when faced with difficulties (Kato *et al*., 2022), continuously learning and developing adaptive capacities (Sánchez-Zamora *et al*., 2016), although dependence on informality can pose challenges on their long-term sustainability (Nemes *et al*., 2023).

This study analyzes adaptive mechanisms of a livestock microenterprise in Tantoyuca, Veracruz, specializing in the fattening of semi-confined cattle, in the face of the disruption caused by the pandemic. The objective was to demonstrate that the microenterprise's adaptive capacity emerged from the synergistic connection between pre-existing territorial resources (natural and productive), operational adaptation capacity (process flexibility), and local support networks (social capital). This hypothesis establishes that this systemic connection contributes to maintaining the socioeconomic sustainability of the production unit. The study provides a conceptual framework for understanding the adaptation mechanisms in livestock systems in the face of external disruptions, with relevance to both the academic field and the practical management of production units in rural contexts.

THEORETICAL FRAMEWORK

This study is framed within the socio-territorial approach to resilience, an interdisciplinary theoretical perspective that analyzes how rural communities build socioeconomic sustainability through the integrated management of material resources, social capital, and local knowledge (Torre, 2025; Zhikharevich *et al*., 2021).

The research is situated in the dichotomy between two conceptual models: firstly planned resilience, based on specialized infrastructure, standardized

protocols, and high levels of formalization (Mu *et al*., 2021; Tittonell *et al*., 2021); and secondly, emergent resilience, which arises from local action capacity, tacit knowledge, and informal cooperation networks (Beckmann *et al*., 2021; Herlina *et al*., 2024).

We propose that in highly vulnerable contexts like the one studied, territorial resilience does not arise exclusively from one model or the other, but from the dynamic articulation between both poles. Although the literature has separately documented the importance of social capital (Ali *et al*., 2022) and operational adaptability (Herlina *et al*., 2024 few studies analyze empirically —or take a longitudinal approach— to how these elements are articulated in livestock microenterprises to generate resilience in the face of a specific disruption, such as occurred during the COVID-19 pandemic. This conceptual approach offers a relevant analytical framework for understanding the adaptive strategies of livestock microenterprises, in the face of external disruptions.

Territorial resilience and adaptability

The literature on resilience in agri-food systems is analyzed primarily with reference to two models. The first corresponds to planned or anticipatory resilience, which relies on specialized physical infrastructure (cold chains, efficient irrigation systems), standardized protocols and high investment in technology to mitigate risks in large-scale chains and improve their response capacity to crises (Mu *et al*., 2021; Tittonell *et al*., 2021). The second model corresponds to emergent or reactive resilience, prevalent in rural microenterprises with limited access to formal resources, which depend on operational flexibility, tacit knowledge, individual agency, and social capital to generate contextual and immediately applicable solutions to disruptions (Beckmann *et al*., 2021; Herlina *et al*., 2024).

Territorial resilience emerges from the integration of operational flexibility and cultural roots, allowing seemingly small systems to demonstrate high adaptive capacity (Assumma *et al*., 2021). This adaptability is built on collective processes of contextualized learning and innovation, where local knowledge and community structures operate as fundamental support mechanisms (Tittonell *et al*., 2021; Fernández-Blanco *et al*., 2022). The effectiveness of these responses critically depends on organizational flexibility and collaborative resource management, as demonstrated by African and South African cooperatives during COVID-19, by combining traditional knowledge with practical innovations (Francesconi *et al*., 2021; Habiyaremye, 2021).

Studies show that the resilience of food systems does not depend exclusively on the scale of production, but on the architecture of their supply chains and the capacity to articulate socio-territorial resources. From a socio-territorial perspective, resilience transcends the notion of recovery to be conceived as

a dynamic and constructive process through which communities mobilize their resources, social capital, and knowledge to confront crises (Torre, 2025; Zhikharevich *et al*., 2021; Brunetta *et al*., 2019). This approach reconceptualizes territory as a social construct where economic, cultural, and political dimensions are articulated to generate specific adaptive responses (Sánchez-Zamora *et al*., 2016).

In this sense, the literature shows that effective resilience does not depend solely on physical infrastructure or economies of scale, but on the capacity of local actors to reorganize their production systems in the face of externalities. In this regard, Suri (2025) and Li (2023) identify five principles to guide agri-food resilience: diversity, connectivity, feedback, learning, and polycentric governance, where different actors collaborate to manage their limited resources through their adaptive capacity, institutional diversity, and autonomy in decision-making. For their part, Yusriadi and Kaslin (2025) and McAreavey (2022) propose that resilience in rural communities is built from the interaction between territorial governance, social capital, and local innovation, which coincides with the logic of family economic units, which are sustained more by community ties than by technological infrastructure.

Social capital and relational assets

Social capital is an intangible asset that enables the collective mobilization of resources in the face of crises (Carmen *et al*., 2022). In rural contexts, it manifests itself in networks of trust, norms of reciprocity, and cooperation mechanisms that facilitate the reduction of transaction costs and generate adaptive solutions, ensuring continuity in contexts of disruption (Panday *et al*., 2021). In this sense, during the pandemic, these networks demonstrated their importance by maintaining the flow of trade through long-term relationships, even when global channels collapsed (Ali *et al*., 2022; Ušča and Tisenkopfs, 2023).

However, while social capital facilitates collective action, it can generate exclusions towards external actors or younger generations without consolidated ties (Baycan and Öner, 2023). Therefore, relationship-based collaboration constitutes a strategy to overcome structural disadvantages, although it can generate its own limitations, such as lack of scalability and exclusion of external actors (Beckmann *et al*., 2021). In this regard, Aldrich and Meyer (2015) point out that, following natural disasters, communities with a higher density of social ties recover faster than those with greater material resources, but less collaboration and cooperation. Similarly, Steiner *et al*. (2023) documented that social capital is a trigger for rural innovation, although its success depends on the ability to expand ties beyond the immediate community.

Tacit knowledge and endogenous innovation

The adaptive capacity of rural microenterprises is largely sustained by their internal innovation processes, the product of tacit knowledge, practical know-how, and experiential expertise accumulated by stakeholders (Herlina *et al*., 2024). This deeply contextualized knowledge enables rapid implementation under uncertain conditions without relying on formal protocols, thus forming the basis for "innovation from within." This mechanism is particularly crucial for organizations with limited access to technological or financial resources, as it allows them to mobilize endogenous intangible assets to generate pragmatic solutions to disruptions.

The effectiveness of this model has been corroborated in rural contexts globally. In South Africa, Francesconi *et al*. (2021) documented how agricultural cooperatives confronted the pandemic by reorganizing their marketing systems, drawing on their members' tacit knowledge and pre-existing relationships of trust. Similarly, in Latvia, Ušča and Tisenkopfs (2023) observed that small producers activated collaborative networks with urban consumers, where reciprocity and mutual trust allowed for the establishment of deferred payment systems and alternative delivery points. These cases share a common pattern: structured improvisation based on local relational and cognitive resources and the activation of trust-based networks, which reduce transaction costs and facilitate coordination in the face of crises. As summarized by Herlina *et al*. (2024), this endogenous innovation process reveals that resilience in rural systems does not depend primarily on exogenous inputs, but on the ability to activate and recombine pre-existing human and relational capital.

Short marketing circuits

Short marketing circuits have proven to be economically and socially resilient models during disruptions such as the COVID-19 pandemic (Thilmany *et al*., 2021; Jia *et al*., 2024). Their structure, based on geographic proximity and the reduction of intermediaries, allows producers to maintain stable incomes, agile communication, and operational flexibility, while strengthening relationships of trust with local consumers (Ali *et al*., 2022). During the pandemic, these circuits demonstrated greater flexibility and adaptability than long chains, sustaining the marketing of agri-food products in Latin America and Europe (Ali *et al*., 2022; Ušča and Tisenkopfs, 2023).

In this regard, Tittonell *et al*. (2021) highlight that local exchange circuits in Latin America not only mitigate the impacts of health crises, but also promote food sovereignty and the participation of small producers in alternative markets. Additionally, Lyall *et al*. (2021) point out that short circuits generate social and environmental benefits by reducing the ecological footprint and reinforcing territorial identity. In this sense, Montalvo *et al*. (2024) argue that

these channels constitute a viable strategy for resilience and sustainability in current agri-food systems.

Critical perspective: sustainability and informality

The relationship between sustainability and resilience is a topic of academic interest. The literature suggests that both properties should be analyzed in an integrated manner, as environmental and social sustainability constitute operational resilience (Stein and Santini, 2022; Michel-Villarreal, 2023). Sustainability practices (efficient use of local resources, building social capital) develop resilience capacities (flexibility, adaptability, collaboration). However, in rural economic units, limitations linked to dependence on informality and the lack of institutionalized governance mechanisms persist (Beckmann *et al*., 2021; Stein and Santini, 2022).

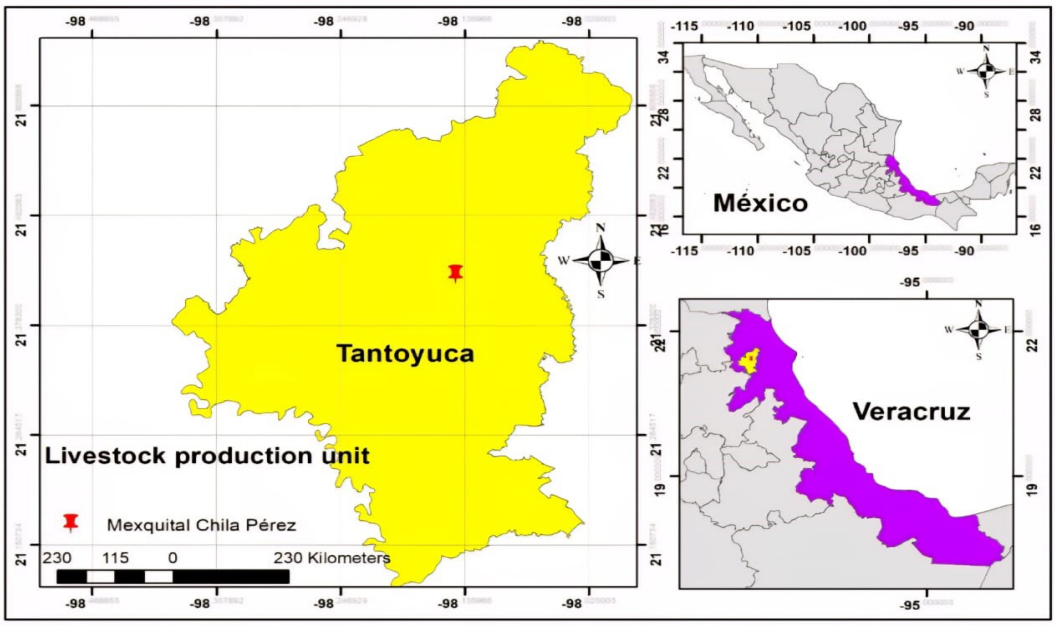
In this sense, although informality guarantees flexibility and the capacity for improvisation in the short term, it can become a structural barrier to long-term competitiveness. The absence of formal protocols, while favoring rapid adjustment, limits the extent models can be replicated and restricts access to more strictly controlled markets. Therefore, recent studies promote hybrid frameworks that combine the adaptability of informal systems with elements of formalization that guarantee sustainability over time (Young, 2016). Here, the sociocultural dimension, with intergenerational relationships, acts as a mechanism for transmitting local knowledge and buffering against crises (Wu and Yuan, 2023); this constitutes a basis for building operational adaptation strategies in rural family microenterprises.

METHODOLOGY

Study area and case study

Research was carried out in the municipality of Tantoyuca, Veracruz, a representative region of rural Mexico, with medium to high marginalization rates and an economy based predominantly on primary activities. In northern Veracruz, livestock activity is classified into three groups: conventional (90%), transitional (8.4%), and business (1.6%) (Méndez-Cortés *et al*., 2019). According to the latest census, the municipality had 1,807 cattle production units, equipped with: watering holes (39.6%), feedlots (6.3%), forage silos (7.3%), and feed mixers (2.4%) (INEGI, 2022).

Within this context, the community of Mezquital Chila Pérez (Figure 1) was selected as an emblematic case. In condensed form, this community represents the area's socioeconomic dynamics, deeply linked to conventional and semi-confined cattle ranching. The local productive structure is characterized by the predominance of family micro-enterprises, operating under the logic of family economy and self-consumption, with a strong dependence on local resources



Source: self-elaborated.
Figure 1. Geographic location of the livestock production unit (LPU) specialized in fattening semi-stabled cattle, in the community of Mezquital Chila Pérez, Tantoyuca, Veracruz, Mexico.

and community cooperation networks. This selection allowed for an in-depth examination of the mechanisms of territorial resilience in a context of high socioeconomic vulnerability, albeit with a significant adaptive capacity based on social capital and local knowledge.

Research design

Our research adopted a longitudinal case study design to examine the disruptive effects of the COVID-19 pandemic on the previously described LPU. The design contemplated the monitoring of three complete fattening production cycles (90 days each), corresponding to the pre-pandemic (batch zero, as a baseline), pandemic (April-June 2020), and post-pandemic (September-November 2020) periods. This strategic selection of time intervals made it possible to capture significant variations in the LPU's operation during the critical phases of disruption and recovery, in accordance with the systemic approach to regional economic resilience proposed by Sutton and Arku (2022).

Techniques and systems used to collect data

The data collection process combined qualitative and quantitative methods to triangulate information. Fieldwork was organized into three main systems. Firstly, semi-structured interviews were conducted with four producers,

three workers, and two members of the local livestock association, focusing on adaptation strategies, decision-making processes, and the dynamics of trust networks during the crisis. Secondly, direct observation of productive activities was carried out. This phase included monitoring two 50-head farms for 90 days during critical periods (April-June 2020, pandemic phase; September-November 2020, post-pandemic phase), using data from a zero farm as a pre-pandemic comparison to establish operational and profitability baselines. Thirdly, a documentary analysis of the LPU's historical records was conducted, including purchase and sale records, livestock weights, input inventories, and commercial transaction receipts.

Data analysis procedure

Data analysis was carried out in two consecutive and complementary phases: (1) supply chain and production cost analysis.

Supply chain analysis: a hierarchical analysis model (Stringer *et al*., 2007) was applied, adapted to the context of rural microenterprises (Sánchez-Galván *et al*., 2019). This model allowed the chain to be disaggregated into functional links, allowing for an integrated assessment of its productive efficiency, quality attributes, and resilient response capacity in the face of disruption (Mu *et al*., 2021). Production cost analysis: a comparative analysis of total costs and their structure was conducted across the three production cycles. This analysis considered four categories: 1) labor and depreciation costs, 2) infrastructure maintenance, 3) acquisition of inputs (livestock, feed, veterinary products, and fuel), and 4) marketing and certification costs. This methodological sequence integrated operational, economic, and social dimensions, making it possible to identify both vulnerabilities and adaptive capacities in family livestock systems in the face of external disruptions. Thus, it constitutes a comprehensive framework for demonstrating territorial resilience processes in livestock microenterprises and empirically compares how LPUs respond to crises by articulating structural and operational adaptations.

RESULTS

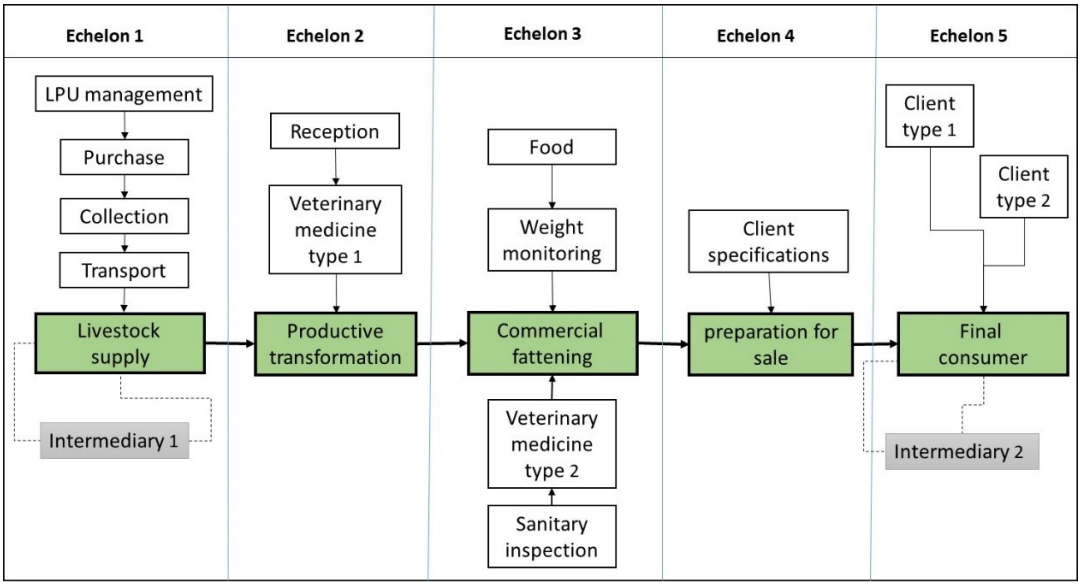
Supply chain

The LPU under study, which covers 38 hectares distributed across five functional divisions, fulfills the criteria for a microenterprise that comprises with the Law for the Development of the Competitiveness of Micro, Small, and Medium-Sized Enterprises (Official Gazette of the Federation - DOF, 2023). The surface area includes 155,913.7 m² of grazing land, with specific areas for veterinary reception (423.5 m²), storage (381.2 m²), nursing (841.5 m²), and pre-marketing feeding (9,248.3 m²), with support from three water collection basins, used for supply. This infrastructure, although limited, made it possible to sustain the

fattening cycles under a semi-stable system. The operating model relies on two workers and economically supports three families, with annual sales of ≤$4 million MXN (microenterprise threshold). This configuration demonstrates a high dependence on local resources, reinforcing the importance of territory as a basis for resilience.

Figure 2 shows the supply chain of a LPU specialized in fattening semi-stabled cattle for sale on the hoof; it is structured into five interconnected links: (1) livestock supply, (2) productive transformation, (3) commercial fattening, (4) preparation for sale and (5) final consumer (local/global markets). In this process, the cattle producer is the central axis, articulated by veterinarians (from basic care to management of complex pathologies); administrative staff (commercial management, legal procedures and advice); network of intermediaries, composed of: local breeders (specializing in calves 6-10 months, 160-200 kg); distributors (in charge of final marketing); destination markets, differentiated between: industrial fattening plants, which complement the production cycle and local merchants (direct sales to the final consumer).

The specialized supply chain for fattening semi-stabled cattle for sale on the hoof begins with a strategic sourcing process that combines local and external resources. The production unit acquires batches of cattle (50 heads weighing 160-200 kg) by means of regional networks and using its own transportation. The production process is structured into standardized 90-day cycles, with differentiated veterinary protocols: basic treatments (87% of cases) for



Source: self-elaborated from fieldwork information.

Figure 2. Supply chain of a LPU specializing in fattening semi-stabled cattle.

prevention and specialized care for complex pathologies, discarding animals that manifest no therapeutic response within seven days to preserve the health of the herd and providing a balanced diet (70% commercial, 30% local). In the pre-commercial phase, live cattle presentation protocols are implemented, including bathing, cleaning, and health checks, to meet the demands of bifurcated markets: industrial fattening plants (60% of sales) and local retailers (40%, focused on weight/age). During the pandemic, 100% of transactions were conducted through trusted networks (68% with repeat buyers), avoiding intermediaries. The commercial strategy articulates geographic scale: 92% of sales in local exchange circuits (<50 km) and 22% in global chains (states of Hidalgo and Querétaro). This result demonstrates the strength of social capital, as an "invisible infrastructure," that sustained operations in a context of disruption.

Structure of production costs

Production costs in the semi-stable system showed a heterogeneous distribution throughout the fattening cycle. In the first 60 days, direct and indirect labor represented 20.9% of total costs, while in the final phase (days 61-90), expenses mainly covered mandatory animal health procedures (TBR/BR tests, reports confirming negative results to medical tests for tuberculosis and brucellosis) and documentation for the National Individual Cattle Identification System (NICIS) (a unique, permanent, and unrepeatable individual number for each animal's life), reaching 52.4% of the total (Table 1). This distribution reflects the significant impact of regulatory requirements on the cost structure, particularly during the marketing stage, where procedures for interstate livestock transport generate a financial burden in the final phase of the cycle. Table 1 shows that regulatory requirements significantly affect the marketing

Table 1. Production costs in a semi-stable system for cattle fattening for sale on the hoof.

Concept	1 to 30 days	31 to 60 days	61 to 90 days
Direct and indirect labour (%)	69.9	74.56	32.8
Tools and equipment (%)	4.8		
Tool maintenence(%)	2.4	3.1	1.1
Consumables and cleaning supplies (%)	20.9	20.3	8.9
Electronic invoicing (%)			0.5
NICIS documentation and (TBR and BR) tests (%)			55.8
Office and paper work (%)	1.91	2.1	0.9
Monthly subtotal	$10,484.00	$9,834.00	$22,384.00

Source: elaborated by the author based on data collected during fieldwork.
Market prices in Mexican pesos for the period April-December 2020.
*TBR and BR are reports confirming negative results from medical tests for tuberculosis and brucellosis. *NICIS is a Federal Animal Health Law regulation that ensures traceability (SADER, 2023).

stage. This confirms that economic resilience depends not only on the internal capacity to manage operations, but also on the ability to take on regulatory burdens within a limited cost structure.

The production of 300 t of silo (6 ha) required $57,000 MXN (year 2020), with costs distributed between: fallow land (38.6%), labor (28.9%), silage (17.5%), raw materials (8.8%), agrochemicals (3.5%), and fuel (2.6%). This profile, where 67.5% corresponded to land preparation and human labor, characterizes semi-stable fattening systems with high investment in operational processes rather than in external inputs. The low percentages of agrochemicals (3.5%) and fuel (2.6%) reflect a model of low chemical use and optimized logistics.

Impact of the pandemic

The declaration of a health emergency (DOF, 2023) generated widespread logistical disruptions, affecting livestock supply chains in the Huasteca region (incorporating parts of Tamaulipas, Hidalgo, Veracruz, and San Luis Potosí). These disruptions, characterized by mobility restrictions and obstacles to the transportation of inputs, were one of the critical impacts of COVID-19 identified in Mexican micro and small businesses (Ibarra *et al*., 2022). In response, the LPU substituted 38% of the balanced feed with orange peel, a byproduct from the Veracruz citrus industry (Bada *et al*., 2017). This measure caused a 60% increase in the price of the substitute during the first 30 days of the pandemic, raising initial production costs by 18.5% compared to the pre-pandemic period.

During the third quarter of 2020, with the partial reestablishment of supply chains, the LPU decided to implement corn silage production, reducing its dependence on external suppliers, primarily in the states of Hidalgo and Veracruz. Feed costs for the 50-head feedlot experienced significant variations between the pandemic and post-pandemic periods, reflecting both the adaptation strategies implemented and the evolution of input market conditions.

During the pandemic period, the cattle's diet consisted of 80% silage (equivalent to 39.84 tons), which represented 59.8% of the total feed cost, with a value of $99,996 MXN, and 20% balanced feed (7.08 tons), which constituted 38.9% of the cost. Additionally, 1.30% orange peel (2.08 tons) was incorporated as a supplement. The total feed cost during this period amounted to $577,052 MXN, which included $42,702 MXN in production costs.

In the post-pandemic period, the 80:20 ratio between silo and feed was maintained (46.4 t and 11.6 t, respectively), although with an inverted cost structure compared to the previous period: the silo represented 12.1% of the total cost ($72,616 MXN), while the feed was 87.8%. The use of orange peel in the diet was eliminated, which allowed a 27.4% reduction in the total feed cost,

compared to the critical pandemic period. The total cost during this phase was $628,625 MXN, which included $42,702 MXN in production costs.

This adaptive innovation, based on tacit knowledge, made it possible to reduce dependence on external suppliers and stabilize the feeding of batches. The transition from a substitute input (orange peel) to a self-produced resource (silo) demonstrates the microenterprise's ability to reorganize its production system to take advantage of local resources.

Comparative profitability

Production and profitability indicators showed significant variations between the zero, pandemic, and post-pandemic batches (Table 2). The post-pandemic batch recorded a 9.2% increase in initial weight (11.98 t) compared to the pandemic batch (10.27 t), a net gain of $168,775 MXN (+5.3 % vs pre-pandemic) and a profit margin of 21.2%, exceeding the pandemic period by 10.2 percentage points (11.0%). In contrast, the pandemic batch showed a 24.8% reduction in weight gain (4.46 t vs. 5.93 t for the zero batch), associated with the sudden substitution of balanced feed. This shows that the LPU's resilience was not based solely on technical capacity, but on the articulation of three support mechanisms: local resources (self-produced silage and use of agro-industrial by-products), social capital (trusted networks with repeat customers), and tacit knowledge (implementation of adaptive innovations in food programs).

Social capital and relational strategies

The articulation of pre-existing networks of trust emerged as a fundamental support mechanism for the LPU's operational continuity. Analysis of commercial transactions revealed that 68% of buyers were repeat customers,

Table 2. Productive indicators and comparative profitability of live cattle lots in zero lot, pandemic, and post-pandemic scenarios.

Concept	Lot type			% Variation (Post-pandemic vs. Zero lot)
	zero	panemic	post-pandemic	
Initial weight (t)	10.97	10.27	11.98	+9.2%
Weight gain (t)	5.93	4.46	5.74	-3.2%
Sale ($/kg) price	45.59	44	45	-1.3%
Herd weight at the end of 90 days (t)	16.9	14.73	17.72	+4.9%
Income ($) per lot	770,471	648,120	797,400	+3.5%
Production cost ($)	610,256	577,052	628,625	+3.0%
Net profit ($)	160,215	71,068	168,775	+5.3%
Relative profitability (Profit/Final weight, $/t)	9,480	4,823	9,524	+0.5%
Profit margin (Profit/Income, %)	20.8%	11.0%	21.2%	+0.4

Source: elaborated by the authors based on data collected during fieldwork and local market costs (prices in Mexican pesos, 2020).

with whom a commercial relationship based on trust and reciprocity was maintained. This relational network allowed 100% of sales to be made during the pandemic by means of verbal agreements, completely avoiding the use of intermediaries and ensuring a critical revenue stream. Geographically, this strategy materialized in that 92% of sales were made within a radius of ≤50, prioritizing local marketing channels and reducing dependence on distant markets. At the same time, the disruption of external supply chains activated informal adaptation mechanisms, such as the tacit exchange of information on input substitutes. This resulted in the replacement of 38% of the balanced feed with orange peel, a byproduct of the local citrus industry. However, this reactive measure increased the cost of this alternative input by 60% during the first 30 days of the crisis. In response, the LPU implemented autonomous corn silage production at a later stage. This, combined with the partial restoration of supply chains, resulted in a 27.4% reduction in total feed costs in the post-pandemic period, compared to the height of the crisis.

Territorial resilience mechanisms in the livestock production unit

The study showed that the LPU's territorial resilience was sustained by three support mechanisms: local resources, social capital, and tacit knowledge (Table 3).
Firstly, harnessing local resources made it possible to reduce dependence on external inputs through the use of available land, silage production, and the incorporation of agro-industrial byproducts.
Secondly, networks of trust established with repeat buyers guaranteed the continuity of sales during the pandemic and ensured liquidity in the absence of formal contracts.
Finally, the producers' accumulated experience enabled innovative responses, such as the temporary substitution of balanced feed and the transition to

Table 3. Territorial resilience mechanisms in the Livestock Production Unit (LPU).

Support	Evidence	Impact
Local resourses	38 ha distributed in functional areas; three water storage tanks; production of 300 t of silage on 6 ha; use of orange peel as a substitute input.	Reducing dependence on external inputs; stabilizing food costs; reorganizing territorial resources.
Social capital	68% of sales were to returning customers; 92% of transactions took place in local exchange circuits ≤50; continued sales during the pandemic through trust agreements.	Maintaining liquidity; reducing commercial risks; strengthening community cohesion.
Tacit knowledge	Replacing feed with orange peel; transition to self-produced silage; decisions based on intergenerational experience.	Adaptive innovations; operational flexibility; recovery of profit margins.

Source: self-elaborated.

autonomous silage production, which favored the recovery of profit margins. The results confirm that territorial resilience is not explained by a single factor, but rather by the integration of material resources, community ties, and practical knowledge. Its relevance lies in demonstrating that even a microenterprise with limited infrastructure can sustain its operations and improve its performance in the context of a global crisis, when it manages to coherently integrate these three aspects.

These mechanisms explain how microenterprises maintained their operations during the health crisis and improved their performance during the recovery phase, confirming that territorial resilience in small-scale systems depends on the integration of resources, community relationships, and intergenerational learning.

DISCUSSION

Systemic articulation of resilience

Results reveal that the resilience of the livestock microenterprise in Tantoyuca was sustained by the articulation of local resources, social capital, and tacit knowledge. This synergy not only guaranteed productive continuity during disruption caused by the pandemic but also enabled an accelerated economic recovery, with profit margins that exceeded pre-pandemic levels. These findings reinforce the hypothesis and provide empirical evidence on the mobilization of socio-territorial assets to confront crises, transcending conventional resilience models (Tittonell *et al*., 2021; Mu *et al*., 2021).

Unlike studies that favor planned models based on standardized infrastructure and protocols, this case exemplifies an emergent and reactive resilience model upheld by socio-territorial assets. The organization of the LPU coincides with the "articulated efficiency" described by Arrieta-González *et al*. (2022), where the optimization of local resources, under conditions of infrastructural limitations, increases the adaptive capacity and operational sustainability of the system, a finding reported by small-scale Mexican livestock units (Méndez-Cortés *et al*., 2019).

Social capital as invisible infrastructure

The articulation of pre-existing trust networks was essential for operational continuity. 68% of buyers were repeat customers, and 92% of sales were made on local exchange circuits of less than 50 km. This result coincides with Ali *et al*. (2022) and Thilmany *et al*. (2021), who identified that short chains were more stable than global markets. This corroborates that resilience in these systems emerges from the articulation of endogenous resources and proximity circuits, aligning with the framework of inclusive short chains as a strategy for risk reduction in Mexican agricultural activity (Bautista-Santos *et al*., 2021).

Unlike Ušča and Tisenkopfs (2023) in Latvia, where resilience depended on collective structures, in Tantoyuca, it was sustained by the individual action of the producer and their network of trust. This social capital acted as "invisible infrastructure" (Sánchez-Zamora *et al*., 2016), with the paradox that informality ensured income in the short term, although it limits scalability, can exclude new actors (Baycan and Öner, 2023) and keep prices below formal markets (Arrieta-González *et al*., 2022).

Operational adaptability and endogenous innovation

Replacing 38% of the feed with orange peel—a local by-product (Bada *et al*., 2017)—initially increased costs by 60%, although it demonstrated operational flexibility (Mu *et al*., 2021). The subsequent transition to autonomous corn silage production reduced feed costs by 27.4%, exemplifying "innovation from within" (Herlina *et al*., 2024), where practical knowledge generated contextual solutions, while avoiding external dependence. However, this dependence on tacit knowledge reveals a structural limitation: as it is not formalized, it restricts the scalability and transferability of knowledge (Sánchez-Galván *et al*., 2019). Thus, operational adaptability is a double-edged sword: a source of reactive resilience and also a barrier to the transition to scalable models.

Paradoxes and dilemmas of informality

The observed resilience emerged from the synergistic articulation of the three support mechanisms, validating the notion of resilience as a constructed socio-territorial process (Sánchez-Zamora *et al*., 2016; Torre, 2025). However, a fundamental paradox emerges: the same informality that guaranteed survival—networks based on trust, verbal agreements, uncodified tacit knowledge—emerges as a barrier to long-term competitiveness. This manifests itself in two predicaments: 1) dependence on relational networks can exclude new actors (Baycan and Öner, 2023), and 2) the absence of formal protocols limits knowledge transferability and the transition toward efficiencies of scale (Beckmann *et al*., 2021). This paradox reflects a fragile and dynamic equilibrium: while formal models prioritize predictability and efficiency (Mu *et al*., 2021), emerging ones prioritize immediate adaptability, even at the cost of temporary lower productive efficiency and fragile sustainability. The challenge is to build "socio-territorial bridges" (Torre, 2025) that preserve the adaptive advantages of informality, while facilitating selective formalization processes.

Limitations and future perspectives

While the model demonstrated socioeconomic resilience, the intensification of local resource use (native grasses) and input substitution could have

unmeasured environmental implications in this study, constituting a limitation and future line of research (Stein and Santini, 2022). Environmental sustainability remains a critical component for long-term viability.

Furthermore, the synergy between sustainability and resilience is confirmed (Michel-Villarreal, 2023): the use of local by-products not only reduces external dependence, but also builds adaptive capacity. Endogenous innovation (Herlina *et al*., 2024) and the socio-cultural substrate (Wu and Yuan, 2023) —transmitted intergenerationally— were critical resources, which show how economic resilience is linked to cultural resilience.

CONCLUSIONS

This study demonstrated that territorial resilience in livestock microenterprises in Tantoyuca, Veracruz, during the COVID-19 pandemic emerged from the dynamic articulation of three interconnected support mechanisms: local resources (land, water and agro-industrial by-products), social capital and short marketing circuits (trust networks, recurring customers and local sales) and tacit knowledge and operational flexibility (endogenous innovation and contextual adaptation).

Results confirm that it was the synergy between these factors—and not their isolated existence—that allowed the productive unit to maintain its operations, recover economically and even surpass its pre-pandemic margins. However, a central paradox was identified: the same informality that guaranteed short-term resilience (verbal agreements, uncodified knowledge and flexible networks) can limit long-term competitiveness and scalability, as well as reproduce exclusionary dynamics for external actors or new generations.

This case reaffirms that territorial resilience is not a static or passive attribute of geographic space, but rather a socially constructed process, rooted in the capacity for local autonomous action, cooperation, and contextualized adaptation. These findings conceptually redefine it as the result of active and dynamic strategies that articulate local scales with external markets through the deliberate mobilization of endogenous resources, the activation of collaborative networks, and the implementation of contextualized innovations.

This research constitutes a comprehensive framework to demonstrate territorial resilience processes in livestock microenterprises and empirically contrast how livestock production units (LPUs) respond to crises by articulating structural and operational adaptations.

Resilience strategies in rural contexts must recognize and enhance these interconnections and also actively address the inherent dilemmas concerning immediate adaptability, as opposed to future sustainability. Lines of research are being opened in order to predict the environmental viability of these

strategies, their replicability in contexts with fewer relational resources and design hybrid mechanisms that will integrate the flexibility of emerging models with the advantages of selective formalization.

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