

Biosecurity practices in live animal markets in Armenia, Azerbaijan, Georgia, and the Republic of Moldova supply chains: A ruminant-focused assessment

Sarah Oste^a, Daniel Beltrán-Alcrudo^b, Mark Hovari^b, Mikayel Haykuni^c, Nicolae Starciuc^d, Alberto Allepuz Palau^{a,*}

^a Departament de Sanitat i d'Anatomia Animals, Facultat de Veterinària, Universitat Autònoma de Barcelona, Edifici V, Travessera dels Turons s/n, Bellaterra, Cerdanyola del Vallès, Barcelona 08193, Spain

^b Food and Agriculture Organization of the United Nations (FAO), Regional Office for Europe and Central Asia, 20 Kalman Imre utca, Budapest H-1054, Hungary

^c Strategic Development Agency, 3 Sergey Mergelyan, Yerevan 0070, Armenia

^d Technical University of Moldova, Faculty of Veterinary Medicine, MD-2004 bd. Stefan cel Mare, 168, Chisinau, Moldova

ARTICLE INFO

Keywords:

Biosecurity
Live animal markets
Livestock supply chains
Ruminants
Southern Caucasus
Eastern Europe

ABSTRACT

Live animal markets (LAMs) are central to livestock trade but can also facilitate the spread of endemic or emerging diseases, making biosecurity a highly relevant tool for risk reduction. As such, this study evaluates biosecurity practices and identifies potential gaps in implementation in LAMs trading ruminants in Armenia, Azerbaijan, Georgia, and the Republic of Moldova. Across all four countries, 41 markets were visited from April to July 2025. Biosecurity practices were assessed through visual observation and face-to-face interviews with market managers and users, using structured surveys. Results showed that although some measures were applied, significant gaps in biosecurity remained, including a lack of infrastructure in some LAMs, partial segregation, inadequate cleaning and disinfection of animal holding areas, and minimal post-market quarantine of traded animals, among others. Nevertheless, LAMs with personnel trained in biosecurity implementation more consistently and comprehensively applied measures, regardless of structural limitations. Both managers and users expressed interest in improving biosecurity, highlighting opportunities for context-specific interventions through sustained stakeholder engagement and infrastructural improvements. Beyond these findings, this study piloted a survey-based assessment intended for future comparative assessment and longitudinal monitoring of biosecurity in LAMs.

1. Introduction

Live animal markets (LAMs) are essential for livestock trade, particularly in low- and middle-income countries. They facilitate smallholder participation in livestock supply chains, thus supporting local economies, rural livelihoods, and food security [61,62,64–67]. Concurrently, LAMs create conditions conducive to the emergence and spread of infectious diseases [19]. Trade networks and markets have been identified as a major driver of the rapid transboundary spread of diseases by aggregating animals from different species and origins [38]. The circulation of animals through these systems increases the number of contact points, and consequently, the risk of pathogen transmission and recirculation within and between regions [20,25,26,52,7].

In Armenia, Azerbaijan, Georgia, and the Republic of Moldova (hereafter “Moldova”), animal movement and trade networks, some of which occur outside official registration and traceability systems, along with often under-resourced public veterinary services, allow the continued circulation of different endemic or emerging transboundary animal diseases (TADs) such as foot-and-mouth disease, lumpy skin disease, peste des petits ruminants, and brucellosis [2,31,37,48,50]. Situated between Eastern Europe and Western Asia, these countries rely heavily on agropastoral economies, with ruminant production being the most important subsector of both commercial livestock systems and smallholder backyard production [13–16,2]. In this context, LAMs are one of the venues for aggregating, trading, and redistributing ruminants across local, national, and cross-border supply chains. Yet, because they

* Corresponding author.

E-mail address: alberto.allepuz@uab.cat (A. Allepuz Palau).

<https://doi.org/10.1016/j.pvmr.2026.100030>

Received 16 April 2026; Received in revised form 4 July 2026; Accepted 4 July 2026

Available online 7 July 2026

3051-3081/© 2026 The Author(s). Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

operate within a complex epidemiological landscape, they are potential hotspots for disease transmission.

In this context, biosecurity—defined as “a set of management and physical measures to reduce the risk of introduction, establishment, and spread of animal diseases, infections or infestations to, from, and within an animal population” [57]—becomes an extremely relevant tool to mitigate these risks. Livestock market biosecurity can be broadly divided into external biosecurity, which refers to measures aimed at preventing the introduction of pathogens into the market, such as animal health screenings, documentation checks, and transport hygiene at entry, and internal biosecurity, which encompasses measures to reduce pathogen spread within the premises, such as segregation of animals and sanitation of animal holding areas. However, effective biosecurity in livestock markets, and in livestock production in general, also heavily relies on stakeholder awareness, communication, training, and engagement to support the consistent implementation and adoption of these measures. Strengthening biosecurity within LAMs is essential to balance their economic function with disease prevention, yet despite the increasingly recognized importance of such measures, they are rarely systematically implemented in livestock market settings [27,28,32,8,41,42]. Little is known about current biosecurity implementation in LAMs where ruminant trade occurs in our study region, or how stakeholders perceive and prioritize them in practice, resulting in a significant knowledge gap in a high-risk setting.

This study assessed biosecurity practices in live ruminant markets and supply chains in Armenia, Azerbaijan, Georgia, and Moldova. By characterizing market structures, stakeholder practices, and perceptions, we identified gaps in implementation and opportunities to strengthen risk management through context-specific interventions. These findings inform ongoing international and national efforts to enhance disease prevention and control in regional farming systems.

2. Materials and methods

2.1. Study design

This observational cross-sectional study was designed to assess biosecurity practices and their level of implementation in LAMs trading in ruminants across Armenia, Azerbaijan, Georgia, and Moldova. Although the survey initially targeted all nine countries within a regional TAD control initiative in Europe and Central Asia, surveys were only conducted in the four aforementioned countries. The five remaining countries were not included due to a lack of LAMs selling ruminants (Belarus and Ukraine), markets being closed due to disease control operations following recent TADs introduction (Bulgaria and Romania), and the survey not being prioritized by national authorities (Türkiye).

The study was also designed to pilot a survey-based methodology intended for future replication and longitudinal monitoring of biosecurity in live animal markets.

Country focal points (CFPs) contracted by the Food and Agriculture Organization of the United Nations (FAO) provided data on the number and operational status of LAMs in their respective countries, drawing on official registration records, regional FAO databases, and cross-referencing with data collected in previous regional assessments [2]. This provided the most complete listing of known, officially registered active markets available at the time of data collection, though unregistered or informal markets operating outside official oversight were not systematically captured. Markets were eligible for inclusion if they were active at the time of data collection and traded ruminant species. In Armenia and Azerbaijan, where the total number of known active markets is low, a census approach was applied and all identified LAMs were surveyed. In Georgia and Moldova, where the number of officially registered markets was larger, a convenience sampling approach was applied, with the assessment limited to markets that were accessible to CFPs within the allocated fieldwork period. This was further constrained by the operational reality that most LAMs in the region operate only on

specific days, typically weekends or designated market days, meaning that each site visit required individual scheduling and significantly limited the number of markets that could be assessed within the available timeframe. While this approach maximized feasibility under operational constraints, it may have introduced selection bias, and findings for Georgia and Moldova should be interpreted with this limitation in mind.

2.2. Survey design and data collection

We developed two structured questionnaires to collect standardized data across livestock markets: one targeting market managers and one for market users. The content of the questionnaires was informed by a review of relevant literature and expert elicitation. Considering key pathways and risk factors for pathogen transmission within LAMs, and associated biosecurity measures, the survey covered the following aspects:

- Inter- and intraspecies mixing and segregation measures;
- Cleaning and disinfection (C&D) of animal holding areas, waste management, and pest control practices;
- Practices during transport of live animals, such as sharing and C&D of transport vehicles;
- On-site and on-farm quarantine/isolation practices;
- Stakeholder hygiene practices, such as handwashing and personal protective equipment (PPE) use
- On-site slaughter practices, including infrastructure, hygiene measures, and personnel involved.

The content of each questionnaire was tailored to the respondent type. Managers, defined as the person responsible for overseeing market activities, were asked about the overall structure and operations, general animal movements and trade practices, and market-level biosecurity practices, and on-site slaughter practices where applicable. While the frequency and conditions of slaughter were captured, the survey did not include a dedicated question on reasons for on-site slaughter. This gap was identified during peer review and recommended for inclusion in future iterations of the assessment tool. Users, defined as farmers, traders, butchers, or individuals with a combination of these roles, engaged in selling and/or buying ruminants at the market, were asked about their individual trade, transport, and biosecurity practices. To identify potential knowledge gaps, implementation difficulties, and opportunities for raising biosecurity awareness and compliance, both questionnaires also included a section about the interviewees' perceptions and priorities around biosecurity in LAMs.

Both questionnaires were piloted and adapted in collaboration with CFPs at four LAMs in the Central Anatolia region and the Mediterranean Region of Türkiye in February 2025, and at two markets in the Ararat and Armavir regions of Armenia in April 2025. CFPs translated finalized questionnaires in their respective national languages, and translations were validated by experts with a relevant technical background. Both questionnaires are included in the [supplementary materials \(S.1. and S.2.\)](#).

To ensure high-quality data collection and limit social desirability bias, CFPs received training on how to perform biosecurity assessments in LAM contexts. They were instructed to use the structured questionnaires as a basis for semi-structured interviews with open questions, allowing respondents to elaborate on their answers and clarify their reasoning when necessary. A field guide with instructions was also provided to support consistency in data collection across countries (see [Supplementary materials S.3.](#)). This approach was intended to reduce social desirability bias in several ways: open-ended questions discourage simple yes/no responses that respondents might tailor to perceived expectations; probing follow-up questions allow interviewers to explore inconsistencies between reported practices and observed conditions; and the conversational format creates an environment in which

respondents are more likely to reflect on and accurately describe actual practices rather than ideal ones [24,44,5]. Triangulation with direct field observations and photographic documentation provided an additional check, allowing CFPs to identify and reconcile discrepancies between reported and observed practices. Nevertheless, we acknowledge that social desirability bias cannot be fully eliminated in interview-based studies, and this remains a limitation of the current study design.

From April to July 2025, CFPs conducted field visits to LAMs to conduct these assessments in Armenia, Azerbaijan, Georgia, and Moldova. At each market, CFPs were instructed to interview the manager (interviews lasted 40–60 min) and survey at least five market users per site (approximately 10 min per user), prioritizing regular participants actively engaged in trading ruminants. This target was established based on experience from the piloting phase, during which interviewing the manager and five users required at least two hours per market. Given that CFPs were required to visit multiple markets per fieldwork day, often located considerable distances apart, and that most markets operate only on specific days and for limited opening hours, this number represented a pragmatic balance between data richness and operational feasibility. We acknowledge that this fixed minimum did not account for market size, and that a larger sample per market would have been preferable; however, the operational constraints of the fieldwork period precluded this. In practice, the number of users interviewed varied across markets and countries, reflecting differences in market attendance, availability of ruminant traders, and seasonal fluctuations in trade activity. Participant selection was based on convenience sampling, as time constraints and operational settings did not always allow random or representative sampling. In markets without a designated managerial role, reflecting the unsupervised nature of these markets rather than a data collection gap, the manager questionnaire was completed through observation and informal discussions with market users. For questions presupposing the existence of a managerial function, such as training participation or formal protocols, this likely resulted in default negative or not-applicable responses rather than a true assessment of practices, since no such role existed to report on. Conversely, directly observable practices (e.g., segregation, cleanliness, infrastructure) are less likely to be affected and are also less susceptible to social desirability bias than self-reported data, as they could be independently corroborated through observation and photographic documentation. A photographic documentation protocol was thus developed to complement self-reported practices more broadly and was particularly valuable for corroborating the questionnaires completed in markets with no managerial role, where no manager-led account was available to verify against. Photographs were used to compare reported practices with observed conditions, such as the type and condition of animal holding areas, the segregation of different species, flooring type (e.g., beaten sand or dirt, which are difficult to clean and disinfect), and the presence of animals that may serve as mechanical vectors or intermediate hosts for certain diseases, such as dogs, which could pose a higher risk due to their roaming or feral behavior. Amendments were made where discrepancies were identified.

Data presented in this study derive from three complementary sources: market manager interviews, market user interviews, and direct field observations. Manager interviews informed market-level data on infrastructure, biosecurity practices and operational characteristics (Table 1, 3 [market-level rows], 4 [manager rows], 5, 7, and 8). User interviews informed individual-level data on trading practices, transport, and biosecurity behaviors (Table 2 [all rows except number of users per year], 3 [user-level rows], 4 [pre-market health measures taken by users], and 6). The estimated number of market users per year (Table 2) was provided by market managers as an operational estimate. Direct field observations by CFPs complemented the interview data for specific questions where visual assessment was more straightforward than self-report, such as species present, flooring type, and pen infrastructure. Photographs collected during field visits were reviewed by the

Table 1

Characteristics of live animal markets (LAMs) in Armenia, Azerbaijan, Georgia, and Moldova.

Country (n = number of markets)	Armenia (n = 6)	Azerbaijan (n = 10)	Georgia (n = 10)	Moldova (n = 15)
Markets registered with authorities (%)	50 (3/6)	100 (10/10)	100 (10/10)	100 (15/15)
Type of market (%)				
Primary collection	100 (6/6)	30 (3/10)	80 (8/10)	100 (15/15)
Secondary distribution	0	70 (7/10)	10 (1/10)	0
Terminal	0	0	10 (1/10)	0
Supervised markets (%)	50 (3/6)	100 (10/10)	100 (10/10)	100 (15/15)
Personnel per market day (average (min–max))				
Veterinarians	0.7 (0.4–1.0)	1.2 (0.8–2.0)	1.7 (0.9–2.7)	1.0
Officials/administrators	0.3 (0.2–0.4)	1.2 (0.9–2.0)	2.5 (1.7–3.0)	1.0
Species traded (%)				
Cattle	100 (6/6)	100 (10/10)	100 (10/10)	100 (15/15)
Sheep	50 (3/6)	100 (10/10)	60 (6/10)	93 (14/15)
Goats	17 (1/6)	90 (9/10)	50 (5/10)	93 (14/15)
Camelids	0 (0/6)	20 (2/10)	0 (0/10)	0 (0/15)
Pigs	67 (4/6)	10 (1/10)	60 (6/10)	93 (14/15)
Poultry	50 (3/6)	100 (10/10)	20 (2/10)	100 (15/15)
Other ^a	67 (4/6)	10 (1/10)	10 (1/10)	87 (13/15)
Cattle per year (thousands; min–max)	2.7–8.4	37.4–127.4	3.2–10.0	0–0.6
Small ruminants (SR) per year (thousands; min–max)	0.7–1.3	53.6–260.0	3.5–8.4	0.0–1.3
Market infrastructure				
Market setup (%)				
Fully outdoors	50 (3/6)	60 (6/10)	30 (3/10)	27 (4/15)
Both indoor and outdoor areas	50 (3/6)	40 (4/10)	70 (7/10)	73 (11/15)
Market area (m ²)	8666.7	26537.0	12311.5	1806.1

Data source: market manager interviews and field observations.

^a “Other” species include horses, rabbits, and dogs.

first author as a contextual check, and minor amendments were made to survey responses in cases of clear discrepancy between reported practices and observed conditions.

2.3. Data analysis

2.3.1. Data cleaning and preprocessing

Raw data were centralized as digital forms on EuSurvey, a secure, web-based survey platform [12]. From there, they were exported to Microsoft Office Excel for cleaning and coding before analysis. This involved harmonizing spelling and formatting in free-text responses, transforming multiple-choice responses into binary variables, and resolving inconsistencies through clarification with CFPs and the photographic documentation. Free-text and open-ended responses were systematically reviewed and thematically summarized to identify recurring patterns in stakeholder perceptions, priorities, and reported practices. Where responses were sufficiently consistent across respondents, these themes were quantified and integrated into the results and discussion; where quantification was not possible, findings are attributed explicitly to CFP field observations or open-ended interview responses.

Cleaned data were exported to RStudio® [49] for descriptive statistics and regression analysis.

Table 2

Market activity and livestock trading patterns among live animal market users surveyed.

Country (n = number of users)	Armenia (n = 28)	Azerbaijan (n = 43)	Georgia (n = 40)	Moldova (n = 4)
Number of users per year* (thousands; min–max)	4.8–8.4	4.9–9.5	4.4–10.2	2.9–4.7
User roles (%)				
Farmer	82 (23/28)	65 (28/43)	23 (9/40)	75 (3/4)
Trader	4 (1/28)	3 (1/43)	25 (10/ 40)	0 (0/4)
Butcher	10 (3/28)	16 (7/43)	20 (8/40)	0 (0/4)
Combined roles	4 (1/28)	16 (7/43)	32 (13/ 40)	25 (1/4)
Purpose of the visit (%)				
Buying only	57 (16/28)	30 (13/43)	11 (4/40)	0 (0/4)
Selling only	39 (11/28)	26 (11/43)	33 (13/ 40)	100 (4/4)
Both selling and buying	4 (1/28)	35 (15/43)	45 (18/ 40)	0 (0/4)
Other	0 (0/28)	9 (4/43)	11 (5/40)	0 (0/4)
Frequency of market visits (%)				
Weekly or more	7 (2/28)	26 (11/43)	44 (18/ 40)	25 (1/4)
Monthly	4 (1/28)	21 (9/43)	44 (18/ 40)	50 (2/4)
Every 2–3 months	18 (5/28)	30 (13/43)	0 (0/40)	25 (1/4)
A few times per year	39 (11/28)	23 (10/43)	12 (4/40)	0 (0/4)
Once a year or less	32 (9/28)	0 (0/43)	0 (0/40)	0 (0/4)
Mean number of ruminants traded per user and per year				
<i>Sold</i>				
Cattle	2.1	9.1	87.5	— ^a
Sheep	1.0	31.6	51.3	2.0
Goats	— ^a	4.9	12.6	0.0
<i>Bought</i>				
Cattle	5.7	17.1	99.8	— ^a
Sheep	23.3	59.3	62.6	0.0
Goats	— ^a	8.3	11.9	2.0
Mean distance from farm to market^b (km)	21.4	16.1	10.9	26.0

Data source: market user interviews; * number of users per year estimated by market managers.

^a “—” indicates that no interviewed users in the respective country reported buying or selling this species (i.e., all responses were not applicable). Values of 0.0 indicate that while some users reported involvement in transactions for that species, the mean volume traded was zero.

^b Calculated only for users who reported having a farm.

2.3.2. Market-level biosecurity scores and their association with different variables

Each of the 21 market-level biosecurity practices included in the questionnaire directed at market managers was scored 0 (poor or non-existent), 0.5 (partial/intermediate), or 1 (good) and summed up to obtain an overall biosecurity score. Candidate predictors for the score included market type (i.e., primary collection, secondary distribution, or terminal market), professional background of the manager (i.e., farmers or veterinarians *versus* non-exposed to livestock, such as accountants or economists), frequency of operations, animal species present (ruminant and non-ruminant), market setup (i.e., indoor/outdoor or mixed), area of the market, manager's perception of markets as a source of disease transmission, manager's participation in trainings, and presence of awareness materials about animal diseases at the market.

To identify which variables were most strongly associated with the overall biosecurity score, we first examined pairwise associations between each predictor and the outcome. For predictors with a significant association with biosecurity, we calculated Cramer's V to identify pairs of predictors with strong correlations. Following Cohen [9], the interpretation of effect size was based on the largest contingency table in our

dataset (a 4×3 table, $df=2$). The thresholds used were $V < 0.07$ = negligible, $0.07 \leq V < 0.21$ = weak, $0.21 \leq V < 0.35$ = moderate, and $V \geq 0.35$ = strong. Among predictors showing a strong correlation, we kept the variable that was most directly relevant to biosecurity. For example, market type and presence of other species were strongly correlated; therefore, we kept the latter for subsequent analysis. Using the remaining predictors, a stepwise selection based on Akaike information criterion (AIC) was applied to identify the most parsimonious model. These selected variables were then included in an ordinary least squares (OLS) linear regression model:

Equation 1:

$$\text{Biosecurity Score}_i = \beta_0 + \sum_{k=1}^p \beta_k X_{ki} + \varepsilon_i$$

where i indexes markets, β_0 is the intercept, representing the expected biosecurity score when all predictors are at their reference level, X_k are the selected market-level predictors, β_k are their associated effects, and ε_i is the residual error. To account for potential clustering of markets within countries, we then fitted a linear mixed-effects model with country as a random effect:

Equation 2:

$$\text{Biosecurity Score}_{ij} = \beta_0 + \sum_{k=1}^p \beta_k X_{kij} + u_j + \varepsilon_{ij}$$

where i indexes markets, j indexes countries, u_j is the random effect capturing extra between-country variability not explained by the predictors, and ε_{ij} is the residual error for each market. This approach allowed us to account for the potential lack of independence of market observations within each country and to determine whether the associations identified in the OLS model remained significant.

Model assumptions were checked for all models by examining residuals, Q-Q plots, Cook's distance, and variance inflation factors (VIF), and predictor significance was evaluated using F-tests for the OLS model and likelihood ratio tests for the mixed model, comparing the full model against nested models with each predictor removed in turn [59]. The total number of markets included in the regression models was $n = 38$, after excluding three Armenian markets with no designated manager to avoid conflating manager-reported and observation-derived data in a model assessing manager-level predictors (2.2). Given the small country-level sample sizes, regression results should be interpreted as exploratory rather than confirmatory, and replication in larger samples is recommended. Additionally, given the small number of markets with trained managers ($n = 6$), we conducted sensitivity analyses to assess the stability of this effect, including leave-one-country-out and leave-one-observation-out refits, group-level and observation-level influence diagnostics (Cook's distance, DFBETAS), and bootstrapped and profile-likelihood confidence intervals for the training coefficient (see 4.3).

All analyses were conducted in RStudio® using the packages MASS [56], car [18], rstatix [30], lmtest [59], sandwich [58,60], nlme [46], and lme4 [4].

2.4. Ethical considerations

This study was conducted in collaboration with national veterinary authorities and CFPs from each country under the coordination of FAO. Written and/or verbally informed consent was obtained from all respondents before data collection commenced. Participation was voluntary, and interviewees were informed of the study's purpose, the intended use of the data, and their right to withdraw at any time. No personal identifying information was collected, and all data, including photographs, were anonymized before analysis and presentation. As this study focused on collective and operational practices rather than individual behaviors, all data were analyzed and presented in an aggregated

way, generally or by country. All principles of voluntary participation and responsible data handling were adhered to throughout. This work has been approved by an institutional ethics committee.

3. Results

3.1. Market structure and functional characteristics

A total of 41 markets were assessed: 6 in Armenia, 10 in Azerbaijan, 10 in Georgia, and 15 in Moldova (Table 1). In supervised markets, the market manager was interviewed ($n = 38$). CFPs interviewed a total of 115 users: 28 in Armenia, 43 in Azerbaijan, 40 in Georgia, and 4 in Moldova. In Moldova, due to the seasonality of ruminant trading, only 4 LAM users trading ruminants were identified in all the markets visited. The geographic distribution of the LAMs surveyed is provided in Supplementary materials S.4.

Registration and oversight of the assessed markets were generally similar across countries (Table 1). In Azerbaijan, Georgia, and Moldova, all visited markets were registered with the relevant authorities and operated under some form of supervision, typically by a designated market manager. Depending on the country, this role was fulfilled by an official veterinarian, a private veterinarian under government contract, the market owner, or an appointed administrator. In Armenia, only half of the assessed markets were formally registered and supervised; however, LAMs without formal legal status or a registered address were still listed by the national food safety authority and subject to veterinary oversight.

All the markets surveyed in Armenia and Moldova operated as primary collection markets, where producers sold livestock directly to other producers, local butchers, or traders for resale in larger markets. In Azerbaijan, 30% of the visited markets served the same primary collection function, while the remaining 70% functioned as secondary distribution markets, characterized by traders selling primarily to butchers or other intermediaries. In Georgia, 80% of markets operated as primary collection markets, 10% as secondary distribution, and 10% as terminal markets, where traders sold to slaughterhouses or engaged in export activities.

Across countries, all markets traded cattle and most also handled other ruminant species such as sheep and goats. Most markets also traded non-ruminant species, including pigs and poultry. Countries differed in the reported annual volumes of traded ruminants. Azerbaijan recorded the highest volumes of cattle and small ruminants traded per year, while Armenia, Georgia, and Moldova reported substantially lower and more variable annual trade volumes. Market infrastructure characteristics appeared to align with reported trading volumes. The LAMs surveyed were either fully outdoors or featured both indoor and outdoor facilities. Moldova had the smallest market area (1806.1 m²), while the largest areas were recorded in Azerbaijan (26,537 m²).

Fig. 1 illustrates the structural diversity observed across the LAMs surveyed, featuring contrasting market layouts and infrastructure that condition the feasibility of biosecurity implementation.

In addition to market-level characteristics, individual-level data were collected from LAM users to understand their roles, reasons for market attendance, and trading behavior (Table 2). In Armenia, Azerbaijan, and Moldova, most respondents were farmers attending the market to sell ruminants. In Georgia, combined roles were more common, with many respondents identifying as both farmers and traders and engaging in both selling and buying activities.

Weekly or more frequent visits were most common in Georgia, in contrast to Armenia, where many interviewed users visited LAMs only a few times per year or less. Respondents in Azerbaijan and Georgia typically participated in LAM activities on a monthly basis, a pattern reflected in the annual number of ruminants traded per user. In Armenia, trading volumes per user were much lower than in Georgia, which had the highest volume.

The estimated number of market users annually ranged from 1,806



Fig. 1. Structural diversity of live animal markets assessed in the study.

Examples of market layouts and infrastructure illustrating the range of structural conditions observed across surveyed LAMs, from markets with fixed, cleanable infrastructure and defined animal holding areas (A) to markets with open layouts, limited physical barriers, and surfaces that constrain cleaning and disinfection (B). These structural differences influence the feasibility of implementing biosecurity measures and contextualize observed variation in biosecurity practices across sites.

in Moldova to 23,405 in Azerbaijan. Reported ranges in the number of users and volumes of animals traded reflect seasonal fluctuations in market activities, with notable increases during specific periods such as the Easter holidays in Moldova, before and after the pasturing season (i. e., spring and autumn) in Armenia and Georgia, and the Eid and Novruz holidays in Azerbaijan.

Estimates for the number of visitors per year (i.e., general public) vary substantially between countries, largely reflecting the nature of the markets. In Georgia and Armenia, LAMs are very specialized and primarily serve as trading hubs for farmers, traders, etc. In Moldova and Azerbaijan, markets often have a multipurpose nature, with livestock trading occurring alongside the sale of animal products or fresh produce. This setup contributes to higher visitor numbers as these markets also attract more general clientele. The increase in public attendance is further compounded ahead of holidays such as Eid, when people visit markets to select sacrificial animals.

3.2. Operational implementation of biosecurity measures across the market continuum

3.2.1. En route: biosecurity during animal transport

We started by examining transportation practices to and from the markets (Table 3). Most ruminants were transported to the market in privately owned vehicles (Armenia, Georgia, Moldova) or with rented vehicles (Azerbaijan). Loading and unloading facilities were variably available: most of the Armenian (67%), Georgian (70%), and Moldovan (88%) markets had designated areas, but their use was not always consistent.

Cleaning and disinfection (C&D) of transport vehicles was most consistently reported in Armenia (82% reporting “always” or “most of the time”) and Georgia (75%), with lower and more variable implementation in Azerbaijan (44% “always” or “most of the time”) and

Table 3

Overview of animal transport practices and related biosecurity measures.

	Country (n = number of users, number of markets)	Armenia (n = 28, 6 markets)	Azerbaijan (n = 43, 10 markets)	Georgia (n = 40, 10 markets)	Moldova (n = 4, 15 markets)
Market-level	Market has a separate loading/unloading area (%)				
	Yes	33 (2/6)	10 (1/10)	60 (6/10)	88 (13/15)
	No	33 (2/6)	50 (5/10)	30 (3/10)	6 (1/15)
	Yes, but not always used	34 (2/6)	40 (4/10)	10 (1/10)	6 (1/15)
	Market has cleaning and disinfection (C&D) facilities for transport vehicles (%)				
User-reported	Yes	17 (1/6)	0 (0/10)	30 (3/10)	50 (7/15)
	No	50 (3/6)	50 (5/10)	60 (6/10)	0 (0/15)
	Yes, but not always used	33 (2/6)	50 (5/10)	10 (1/10)	50 (8/15)
	Transport method (%)				
	Privately owned vehicle	97 (27/28)	28 (12/43)	83 (33/40)	100 (4/4)
	Rental vehicle	3 (1/28)	46 (20/43)	15 (6/40)	0 (0/4)
	Transporter/transport company	0 (0/28)	26 (11/43)	2 (1/40)	0 (0/4)
	Transport sharing frequency (%)				
	Always	0 (0/28)	26 (11/43)	5 (2/40)	0 (0/4)
	Most of the time	0 (0/28)	40 (17/43)	20 (8/40)	0 (0/4)
	Occasionally	7 (2/28)	14 (6/43)	20 (8/40)	0 (0/4)
	Rarely	4 (1/28)	16 (7/43)	18 (7/40)	25 (1/4)
	Never	86 (24/28)	4 (2/43)	28 (11/40)	50 (2/4)
	Respondent doesn't know ^a	0 (0/28)	0 (0/43)	2 (1/40)	0 (0/4)
	Not applicable ^b	3 (1/28)	0 (0/43)	7 (3/40)	25 (1/4)
	Transport vehicle sanitation C&D frequency (%)				
	Always	71 (10/28)	18 (8/43)	40 (16/40)	0 (0/4)
	Most of the time	11 (3/28)	26 (11/43)	35 (14/40)	25 (1/4)
	Occasionally	7 (2/28)	28 (12/43)	7 (3/40)	50 (2/4)
	Rarely	0 (0/28)	21 (9/43)	3 (1/40)	25 (1/4)
	Never	4 (1/28)	5 (2/43)	0 (0/40)	0 (0/4)
	Respondent doesn't know ^a	0 (0/28)	2 (1/43)	10 (4/40)	0 (0/4)
	Not applicable ^b	7 (2/28)	0 (0/43)	5 (2/40)	0 (0/4)
	Assessment of C&D protocol (%)				
	Ideal	0 (0/28)	0 (0/43)	3 (1/40)	0 (0/4)
	Good	4 (1/28)	12 (5/43)	47 (19/40)	25 (1/4)
	Moderate	56 (16/28)	53 (23/43)	21 (8/40)	25 (1/4)
	Poor	40 (11/28)	35 (15/43)	29 (12/40)	50 (2/4)
	When C&D is performed (%)				
	After every trip	64 (18/28)	65 (28/43)	46 (18/40)	75 (3/4)
	At regular intervals	20 (6/28)	10 (4/43)	50 (20/40)	0 (0/4)
	When there is visible dirt or manure	88 (25/28)	35 (15/43)	6 (2/40)	25 (1/4)
	When transporting animals from different origins	0 (0/28)	3 (1/43)	0 (0/40)	0 (0/4)
	When required by regulations/market management	0 (0/28)	5 (2/43)	0 (0/40)	75 (3/4)
	Where C&D performed (%)				
	At the market	0 (0/28)	50 (22/43)	0 (0/40)	0 (0/4)
	At specialized C&D centers	60 (17/28)	13 (6/43)	54 (22/40)	0 (0/4)
	At the slaughterhouse	0 (0/28)	35 (15/43)	0 (0/40)	0 (0/4)
	At the user's farm	80 (22/28)	93 (40/43)	63 (25/40)	100 (4/4)

Data source: market manager interviews (market-level rows) and market user interviews (user-level rows), supplemented by field-observation.

^a Refers to participants who use rental vehicles or transport companies and are not themselves involved in transportation or C&D of vehicles.^b Refers to participants who bring their animals to the market on foot.

Moldova (25%). Respondents described their C&D protocols, which were evaluated against a three-step “ideal” standard: removal of organic material, high-pressure washing with detergent, and application of disinfectant. Few of the reported protocols met all three steps, with most rated as “moderate” or “poor.” C&D was primarily conducted at the respondent’s farm or in specialized C&D centers and was usually performed after every trip or when vehicles were visibly dirty. Vehicle sharing (i.e., transporting animals from different herds in the same vehicle, at the same time) occurred occasionally in Georgia and more frequently in Azerbaijan. Transporting animals from different sources in the same vehicle did not specifically prompt C&D.

3.2.2. Managing risk at the gate: pre-market biosecurity practices

Biosecurity measures in place before and at LAM entry included physical barriers to entry, health requirements, inspection procedures, and transport-related practices (Table 4). Although the types of

measures were comparable, the extent to which they were implemented differed between countries.

Mandatory vaccination requirements, primarily against anthrax and foot-and-mouth disease in Armenia, and anthrax in Azerbaijan and Moldova [2], were consistently reported by managers in Armenia (100%) and Moldova (94%), and moderately in Georgia (60%), where a risk-based vaccination approach is applied. Notably, no managers in Azerbaijan reported mandatory vaccination requirements despite national legislation mandating vaccination against anthrax for all ruminants, suggesting either limited awareness of requirements or inconsistent enforcement at the market level. Diagnostic testing requirements were most common in Moldova, but less so elsewhere. Armenian (83%) and Moldovan (81%) managers more commonly acknowledged the need for animals to be certified free from certain diseases. Sellers in all countries also reported taking preventive measures before bringing animals to market, including vaccination,

Table 4

Pre-market entry requirements, document checks, and inspection practices.

	Country (n = number of users, number of markets)	Armenia (n = 28, 6 markets)	Azerbaijan (n = 10, 10 markets)	Georgia (n = 40, 10 markets)	Moldova (n = 4, 15 markets)
Market-level	Access restriction (%)	33 (2/6)	100 (10/10)	90 (9/10)	100 (15/15)
	Free-roaming animals can access premises (%)	83 (5/6)	70 (7/10)	40 (4/10)	100 (15/15)
	Pre-market health requirements (%)				
	Mandatory vaccinations or anti-parasitic treatments	100 (6/6)	0 (0/10)	60 (6/10)	94 (14/15)
	Mandatory diagnostic tests	0 (0/6)	0 (0/10)	30 (3/10)	94 (14/15)
	Animals need to be certified free from certain diseases	83 (5/6)	0 (0/10)	50 (5/10)	81 (12/15)
	Documents to be presented at entry (%)				
	No documents	50 (3/6)	100 (10/10)	10 (1/10)	0 (0/15)
	Passports	0 (0/6)	0 (0/10)	90 (9/10)	0 (0/15)
	Health certificates	50 (3/6)	20 (2/10)	40 (4/10)	100 (15/15)
	Vaccination records	33.3 (2/6)	0 (0/10)	60 (6/10)	100 (15/15)
	Transport documents	0 (0/6)	0 (0/10)	50 (5/10)	63 (9/15)
	Inspection at entry (%)				
	Yes	50 (3/6)	20 (2/10)	80 (8/10)	56 (8/15)
	No	50 (3/6)	20 (2/10)	0 (0/10)	0 (0/15)
	Not always/Not all animals	0 (0/6)	60 (6/10)	20 (2/10)	44 (7/15)
	Reasons for denied entry* (%)				
	Generic symptoms of illness	100 (3/3)	0 (0/8)	70 (7/10)	0 (0/15)
	Respiratory symptoms	100 (3/3)	25 (2/8)	80 (8/10)	7 (1/15)
	Digestive symptoms	0 (0/3)	0 (0/8)	0 (0/10)	0 (0/15)
	Lameness or mobility issues	100 (3/3)	0 (0/8)	30 (3/10)	0 (0/15)
	Skin or coat conditions	33 (1/3)	25 (2/8)	50 (5/10)	7 (1/15)
	Missing documents	100 (3/3)	0 (0/8)	40 (4/10)	0 (0/15)
	Instructed procedure after denied entry* (%)				
	Reported to return to premises of origin	100 (3/3)	25 (2/8)	80 (8/10)	53 (8/15)
	None	0 (0/3)	75 (4/8)	20 (2/10)	47 (7/15)
User reported	Pre-market health measures taken by users for animals intended for sale* (%)				
	Does not take measures	4 (1/28)	67 (29/43)	8 (3/40)	0 (0/4)
	Takes measures	50 (14/28)	12 (5/43)	90 (36/40)	100 (4/4)
	Not applicable (doesn't sell animals at the market)	46 (13/28)	21 (9/43)	2 (1/40)	0 (0/4)

Data source: market manager interviews; * pre-market health measures taken by users from user interviews.

* Percentages refer to the proportion of markets reporting each reason for denied entry and the instructed procedure after denied entry among those that conduct entry inspections.

deworming, diagnostic testing, and visual inspection.

Documentation and inspection practices also varied across countries and depended strongly on whether markets had designated supervisory personnel. Requirements for vaccination records, health certificates, transport documents, and animal passports were more consistently implemented in Georgia and Moldova than in Armenia and Azerbaijan.

In Armenia, markets with supervisors reported full compliance, but half of the markets lacked supervisory personnel, leaving no one responsible for enforcing document checks. In Azerbaijan, supervisors were present but did not routinely verify documentation.

Physical inspection practices followed a similar pattern. In Armenia, systematic entry inspections were reported in markets with supervisors, while unsupervised LAMs relied on self-inspection by users. In Azerbaijan, supervisors were present but rarely conducted inspections. Systematic inspections were reported more frequently in Georgia (80%) and Moldova (56%).

Regarding animal health status at entry, in Armenia and Georgia, markets implementing entry inspections typically reported denying entry to animals showing clinical signs of disease (e.g., fever, respiratory or digestive signs, lameness), and market managers reported instructing users to return these animals to their premises of origin, in line with the absence of quarantine facilities within markets. In Azerbaijan and Moldova, entry rejection criteria were less consistently applied or reported, meaning that animals showing clinical signs may not always have been systematically identified or excluded at entry.

3.2.3. Containing risk on-site: internal biosecurity and hygiene

Internal biosecurity practices varied in terms of animal segregation and sanitation procedures of animal holdings, and available hygiene infrastructure.

Reported segregation practices differed across countries, but effective implementation was rarely complete. Based on a composite indicator combining declared segregation measures (by species, age, owner, health status, or a combination thereof) with direct observations on pen mixing and nose-to-nose contact, most markets in all four countries were classified as having partial segregation (Table 5). Species-based segregation was reported in all markets in Georgia, in 70% of markets in Azerbaijan, in 33% of markets in Armenia, and in only 6% of markets in Moldova. Owner-based segregation was common in Armenia (83%), Georgia (80%), Azerbaijan (70%), but less frequent in Moldova (6%). Despite these measures, mixing of animals from different herds still occurred in one-third of markets in Armenia, in all markets in Azerbaijan and Moldova, and in 10% of markets in Georgia. Moreover, nose-to-nose contact was possible in most markets, regardless of formal segregation rules. As a result, only very few markets met the criteria for complete segregation.

As mentioned previously, isolation areas for animals with clinical signs of disease were available in some markets in Armenia and Azerbaijan, and in 50% of surveyed Georgian markets, but their use was generally limited.

Cleaning and disinfection (C&D) of market pens was inconsistently implemented. Half of Armenian markets managers and 90% of those in Azerbaijan reported that pens could not be cleaned or disinfected at all,

Table 5

Internal biosecurity and hygiene practices in live animal markets: infrastructure, cleaning and disinfection (C&D), and animal holding.

Country (n = number of markets)	Armenia (n = 6)	Azerbaijan (n = 10)	Georgia (n = 10)	Moldova (n = 15)
Segregation at market (%)				
None	0 (0/6)	30 (3/10)	0 (0/10)	60 (9/15)
Partial	100 (6/6)	70 (7/10)	60 (6/10)	40 (6/15)
Complete	0 (0/6)	0 (0/10)	40 (4/10)	0 (0/15)
Segregation criteria (%)				
None	0 (0/6)	90 (9/10)	0 (0/10)	94 (14/15)
By species	33 (2/6)	70 (7/10)	100 (10/10)	6 (1/15)
By health status	17 (1/6)	0 (0/10)	0 (0/10)	0 (0/15)
By size or age	17 (1/6)	50 (5/10)	10 (1/10)	0 (0/15)
By owner	83 (5/6)	70 (7/10)	80 (8/10)	6 (1/15)
Ruminants from different herds can be mixed in the same pens	33 (2/6)	100 (10/10)	10 (1/10)	100 (15/15)
Ruminants from different herds can have nose-to-nose contact	83 (5/6)	100 (10/10)	40 (4/10)	100 (15/15)
Isolation area (%)	33 (2/6)	20 (2/10)	50 (5/10)	0 (0/15)
General cleaning and disinfection (C&D) practices for market pens (%)				
Pens cannot be cleaned/disinfected	50 (3/6)	90 (9/10)	40 (4/10)	0 (0/15)
Pens are used as they are, without cleaning	17 (1/6)	10 (1/10)	0 (0/10)	0 (0/15)
Pens are cleaned, but not disinfected	17 (1/6)	0 (0/10)	10 (1/10)	73 (11/15)
Pens are cleaned and disinfected	17 (1/6)	0 (0/10)	30 (3/10)	0 (0/15)
C&D depends on market day or animal type	0 (0/6)	0 (0/10)	20 (2/10)	27 (4/15)
Cleaning method (%)				
No cleaning	67 (4/6)	50 (5/10)	10 (1/10)	0 (0/15)
Dry cleaning	17 (1/6)	30 (3/10)	60 (6/10)	0 (0/15)
Wet cleaning	0 (0/6)	0 (0/10)	0 (0/10)	0 (0/15)
Mixed cleaning	17 (1/6)	20 (2/10)	30 (3/10)	100 (15/15)
Implementation of disinfection (%)				
Yes	17 (1/6)	10 (1/10)	60 (6/10)	13 (2/15)
Yes, but not always performed	17 (1/6)	20 (2/10)	40 (4/10)	27 (4/15)
No	67 (4/6)	70 (7/10)	0 (0/10)	60 (9/15)
Market waste management system (%)				
Solid waste	33 (2/6)	0 (0/10)	100 (10/10)	100 (15/15)
Liquid waste	33 (2/6)	0 (0/10)	70 (7/10)	25 (4/15)
Pest control program (%)	17 (1/6)	0 (0/10)	100 (10/10)	100 (15/15)
On-site facilities for basic diagnostic testing (%)				
Yes	0 (0/6)	0 (0/10)	30 (3/10)	12 (2/15)
Yes, but not always used	0 (0/6)	40 (4/10)	10 (1/10)	0 (0/15)
No	100 (6/6)	60 (6/10)	60 (6/10)	88 (13/15)
Hygiene facilities for stakeholders (%)				
Disinfection facilities for footwear (staff)				
Yes	17 (1/6)	0 (0/10)	40 (4/10)	6 (1/15)
Yes, but not always used	0 (0/6)	20 (2/10)	10 (1/10)	25 (4/15)
No	83 (5/6)	80 (8/10)	50 (5/10)	69 (10/15)
Disinfection facilities for footwear (visitors)				
Yes	17 (1/6)	0 (0/10)	10 (1/10)	0 (0/15)
Yes, but not always used	0 (0/6)	20 (2/10)	20 (2/10)	38 (6/15)
No	83 (5/6)	80 (8/10)	70 (7/10)	62 (9/15)
Components of handwashing facilities (%)				

Table 5 (continued)

Country (n = number of markets)	Armenia (n = 6)	Azerbaijan (n = 10)	Georgia (n = 10)	Moldova (n = 15)
Running water	33 (2/6)	20 (2/10)	100 (10/10)	94 (14/15)
Soap	33 (2/6)	10 (1/10)	100 (10/10)	94 (14/15)
Alcohol-based disinfectants	17 (1/6)	0 (0/10)	60 (6/10)	100 (15/15)
Paper towels	0 (0/6)	0 (0/10)	100 (10/10)	88 (13/15)
Hand dryer	0 (0/6)	0 (0/10)	50 (5/10)	19 (3/15)

Data source: market manager interviews and field observation.

largely due to structural constraints. In contrast, most of the Moldovan markets reported that pens were cleaned but not disinfected (73%). Only a minority of markets in any country performed both cleaning and disinfection, ranging from 17% in Armenia to 30% in Georgia. Dry, wet, or mixed cleaning methods (i.e., both wet and dry cleaning) were used where cleaning was possible, with mixed methods being most common. Disinfection of animal holding areas was either not performed or only implemented under certain circumstances, such as disease outbreaks. Disinfection was never performed in 70% of Azerbaijani markets, 60% of Moldovan markets, and 67% of Armenian markets. Georgian markets showed comparatively better practices, with 60% performing routine disinfection and the remaining 40% doing so intermittently.

In all countries, at least half of the managers reported that C&D facilities for transport vehicles were non-existent in their market, and when they were, they were often not used. Disinfection mats or baths for footwear were uncommon in all countries. Handwashing facilities were common, but the availability of soap, disinfectants, and hand-drying options varied, especially in Armenia and Azerbaijan, which showed the most limited hygiene infrastructure overall.

Solid waste management systems were uncommon, with many markets having no structured system, except in Georgia and Moldova, where waste was removed off-site (100%). Systems such as composting, manure pits, or incineration were rarely reported. Liquid waste management systems were similarly limited: most markets lacked any dedicated system, aside from drainage systems reported in Azerbaijan (10%) and Georgia (60%). Pest control programs were also inconsistently implemented, being reported in only 17% of markets in Armenia and in none of those in Azerbaijan, but in all markets in Georgia and Moldova. Laboratory testing facilities were generally absent, except in a few sites in Georgia and Moldova.

On-site slaughter was reported in six markets in Azerbaijan, occurring routinely in three and rarely (emergency or special request only) in the remaining three. No on-site slaughter was reported in Armenia, Georgia, or Moldova. Among markets where slaughter occurred, practices and infrastructure varied considerably. Two markets had a designated enclosed slaughter area with restricted access, while one market reported slaughter taking place in an open non-designated space with no restricted access. Hygiene measures during slaughter were inconsistent: most markets reported handwashing and cleaning of the slaughter area, but PPE use was only occasional in most cases. Veterinary inspections during slaughter were reported in most Azerbaijani markets, though not always systematically. C&D of slaughter areas was performed in most cases, though frequency and thoroughness varied. Biological waste management was limited, with most markets reporting no specific system. Notably, in the market where slaughter occurred in an open undesignated space, no specific hygiene measures were required and PPE use was only occasional, representing a particular biosecurity and zoonotic disease risk given the proximity to live animals and market visitors.

3.2.4. Closing the loop: on-farm practices and destinations of traded animals

Animals returning from markets may carry pathogens acquired during market activities. In this study, reported movement practices offer an insight into the potential risks associated with post-market practices. Based on user-reported survey responses, market users across all countries reported using multiple trade channels when buying and selling ruminants. LAMs were the predominant channel, with the majority of respondents reporting using them frequently or usually for selling ($n = 51/115$, 44%) and buying ($n = 61/115$, 53%), while farm-to-farm transactions and traders were used less consistently and varied more by country.

Following market transactions, purchased animals were directed towards a range of destinations. Commercial slaughter was the most frequently reported destination ($n = 33/115$, 29%), followed by fattening ($n = 29/115$, 25%) and resale ($n = 29/115$, 25%), with breeding ($n = 14/115$, 12%) and personal consumption slaughter ($n = 15/115$, 13%) less commonly reported. This variability in destinations reflects important differences between countries: in Azerbaijan and Georgia, non-terminal destinations such as fattening and breeding predominated, while in Armenia the higher proportion of slaughter destinations reflects the fact that several respondents were butchers purchasing animals exclusively for immediate slaughter. In Moldova, most reported movements were likewise non-terminal. The lower observed activity levels likely reflect the seasonal nature of ruminant trading in the country; across the 15 markets surveyed, only four individuals engaged in ruminant trading were present and available for interview at the time of data collection.

Despite the continued post-market circulation of animals, quarantine measures (i.e., physical separation from the main production herd, without the possibility of direct or nose-to-nose contact) of newly purchased or unsold animals were infrequently applied ([Supplementary materials S.5.](#)). For newly purchased animals, no quarantine was reported by 82% of Armenian, 84% of Azerbaijani, 56% of Georgian, and 100% of Moldovan respondents. Short quarantine periods (<15 days) were reported mainly in Georgia (41%), followed by Armenia (18%) and Azerbaijan (13.9%), while only a minimal proportion of Georgian and Azerbaijani users (3% and 2%, respectively) reported quarantining animals for more than 15 days. For unsold animals returning from markets, quarantine practices were similarly rare: 96% in Armenia, 86% in Azerbaijan, 65% in Georgia, and 100% in Moldova reported not isolating returning stock. Short quarantine periods (<15 days) were reported in Georgia (35%), Azerbaijan (14%), and Armenia (4%). Users from all countries also reported administering vaccines, dewormers, or antibiotics to newly acquired animals, sometimes during the quarantine period if one is implemented, but often without isolating them from the main herd ([Supplementary materials S.5.](#)).

3.2.5. Stakeholder perceptions, priorities, and communication around biosecurity

Across all surveyed countries, market stakeholders acknowledged that LAMs play a role in disease transmission pathways, although perceptions of risk varied ([Table 6](#)). Users perceived it to be higher than managers and 36% described this risk as “extremely significant,” 54% as “very significant,” and 9% as “moderately significant.” Among managers, 29% considered the risk “extremely significant,” 34% “very significant,” and 37% “moderately significant.”

Users and managers identified largely overlapping biosecurity priorities across countries. Among users ($n = 115$), the most frequently cited measures were vaccinating animals (81%), restricting the entry of sick animals (64%), and having a veterinarian present during market operations (60%). In contrast, quarantine (18%), reliance on trust or social control among users (9%), record-keeping (9%), verification of animal documentation (5%), pest control (4%), and restricted visitor access (3%) were rarely cited ([Table 8](#)). Managers' priorities were broadly consistent with those of users. The presence of a veterinarian

Table 6

Biosecurity perceptions and priorities reported by market managers and users.

	Managers (n = 41)	Users (n = 115)
Perceived role of markets in disease spread (%)		
Not significant at all	0 (0/41)	0 (0/115)
Slightly significant	0 (0/41)	2 (2/115)
Moderately significant	37 (15/41)	9 (10/115)
Very significant	34 (14/41)	54 (62/115)
Extremely significant	29 (12/41)	35 (41/115)
Priority biosecurity measures for live animal markets (%)		
Cleaning and disinfection (C&D) of the market	61 (25/41)	47 (54/115)
C&D of the transport vehicles	37 (15/41)	39 (45/115)
Limit access of sick animals to the market	49 (20/41)	64 (74/115)
Separate animals from different herds	32 (13/41)	11 (13/115)
Inspect animals before entry	61 (25/41)	36 (41/115)
Presence of a veterinarian	81 (33/41)	60 (69/115)
Vaccinate animals	76 (31/41)	81 (93/115)
Quarantine	17 (7/41)	18 (21/115)
Ensure that animals that enter have the appropriate documents	10 (4/41)	5 (6/115)
Restrict visitor access	5 (2/41)	3 (3/115)
Personal hygiene (handwashing, disinfection of footwear, use of appropriate PPE)	27 (11/41)	17 (20/115)
Pest control	29 (12/41)	4 (5/115)
Record-keeping	5 (2/41)	9 (10/115)
Trust and social control among users (e.g., excluding those who bring sick animals)	0 (0/41)	9 (10/115)
Other	0 (0/41)	2 (2/115)

Data source: market manager interviews ($n = 41$) and user interviews ($n = 115$).

(81%), vaccination (76%), inspection of animals before entry (61%), C&D of the market (61%), and restricting the entry of sick animals (49%) were the most frequently reported measures. Quarantine (17%), segregation (32%), and C&D of transport vehicles (37%) were cited less frequently, while record-keeping (5%), restricted visitor access (5%), and trust or social control (0%) were rarely mentioned.

Communication strategies also differed. Managers reported relying primarily on posters, individual advice, and government campaigns to inform users about prevention measures and biosecurity ([Supplementary materials S.6.](#)). However, 86% of users stated they had not seen any awareness materials on market premises ([Supplementary materials S.7.](#)).

Participation in training on biosecurity was reported by 21% of users in Armenia, 17% in Georgia, and 14% in Azerbaijan. Trainings were run either by national government agencies, international organizations (e.g., FAO, WHO), or non-governmental organizations. Among managers, 33% in Armenia and 50% in Georgia reported participating in, and in some cases organizing, similar trainings for market staff.

Information sources for animal health and disease prevention also differed. Veterinarians were the most cited source among users in Armenia and Moldova (100%), Georgia (98%), and Azerbaijan (63%). Other reported sources included the internet or social media (37%), national government agencies (22%), radio or television programs (22%), and family or neighbors involved in farming (22%). Market managers mainly cited veterinarians (95%), the internet or social media (68%), local municipal authorities (49%), and national authorities (38%).

Beyond structured responses, open-ended interview questions and free-text fields revealed recurring themes in stakeholder perceptions and priorities. In Armenia, the large majority of sellers spontaneously reported that they exclusively bring healthy animals to market (11/12 sellers), relying on visual self-assessment rather than objective indicators or documentation. Notably, the same respondents described evaluating the health status of animals they purchased through certificates or veterinary checks, suggesting an asymmetry in how market-exposed and incoming animals are perceived as disease risks. When asked how biosecurity in LAMs could best be improved, the most

frequently cited approaches among users who provided open-ended responses (n = 67) across countries were individual advice from veterinarians (n = 25, 37%), infrastructural improvements (n = 20, 30%), and training or awareness campaigns (n = 20, 30%). Among managers who provided open-ended responses (n = 39), infrastructural improvements and broader institutional support were consistently emphasized (n = 25, 64%), with managers, particularly in Armenia and Moldova, stressing that effective interventions would require the active involvement of cooperatives, veterinary authorities, and local stakeholders, and that training alone would be insufficient without this institutional backing. These themes were consistent across CFP field observations and open-ended responses and are discussed further in 4.2.

3.2.6. Market-level predictors of biosecurity scores and implementation

Results from the mixed model described in Equation 2 were broadly consistent with the OLS model (Equation 1; [Supplementary materials S.8.](#)) but allowed us to account for differences between countries. The analysis included 38 markets out of the total 41 surveyed. Three markets in Armenia were excluded because no market manager was available, and therefore key predictor variables could not be obtained for these observations, making them unsuitable for inclusion in the regression analysis.

The final mixed-effects model (Equation 2) included the presence of non-ruminant species, manager perception of the significance of LAMs as a source of disease transmission, and manager participation in training as fixed effects, with country included as a random effect ([Table 7](#)).

Substantial between-country variability in biosecurity scores was observed (random-effect variance = 7.40; SD = 2.72). Fixed effects alone explained 32% of the variance in biosecurity scores (marginal R² = 0.32) and increased to 73% when including both fixed effects and country-level variability (conditional R² = 0.73).

Among fixed effects, markets with trained managers had significantly higher biosecurity scores ($\beta = 4.70$, SE = 1.38, t = 3.42). Managers who perceived the market as a “very” significant source of disease transmission had higher biosecurity scores compared with those selecting “extremely” significant ($\beta = 3.16$, SE = 1.12, t = 2.82). A similar positive, though non-significant, association was observed for managers rating the market as “moderately” significant ($\beta = 1.65$, SE = 1.53, t = 1.08). The presence of non-ruminant species was associated with lower biosecurity scores, but this effect was not statistically significant ($\beta = -2.30$, SE = 1.41, t = -1.63).

Table 7
Mixed-effects linear regression examining associations between market characteristics, manager training, and perceived disease transmission with overall market-level biosecurity score (random effect: country).

Predictor	Estimate (β)	SE*	t value	Significance
(Intercept)	8.01	1.94	4.14	—
Non-ruminant species (Yes)	-2.3	1.41	-1.63	0.081
Perceived significance of markets as a source of disease transmission (Moderately)	1.65	1.53	1.08	0.009**
Perceived significance of markets as a source of diseases transmission (Very)	3.16	1.12	2.82	0.009**
Trained manager (Yes)	4.7	1.38	3.42	0.0008
Random effect (country)	Variance = 7.40	SD = 2.72	—	—
Residual variance	4.97	SD = 2.23	—	—

Data source: market manager interviews.

* SE = standard error

** Note: p-value for “perceived significance of markets as a source of disease transmission reflects the overall likelihood ratio test for the variable as a whole.

For interpretation, the intercept ($\beta_0 = 8.01$) represents the expected biosecurity score for a market with no non-ruminant species, where the manager rated LAMs as an “extremely significant” source of disease transmission, and with an untrained manager, in an average country. Positive or negative coefficients (β) indicate the expected change in biosecurity score relative to the reference category. For example, markets with trained managers had a score 4.7 points higher on average than those with untrained managers.

The distribution of overall biosecurity scores across all 38 markets included in the model is shown in [Supplementary Figure S.9](#). The substantial between-country variability in biosecurity scores is illustrated in [Fig. 2](#), which also shows the distribution of scores across all markets included in the regression model. Among markets with trained managers (n = 6), biosecurity scores were substantially higher (mean = 14.75, SD = 3.48) compared with markets with untrained managers (n = 32; mean = 6.94, SD = 3.92). However, the small sample size of the trained group should be considered when interpreting this result.

To examine whether differences in biosecurity scores between markets with trained and untrained managers could be explained by differences in market infrastructure, we compared markets across structural characteristics, including market type, operation frequency, setup, area, access control, and presence and volumes of ruminant and non-ruminant species traded ([Table 8](#)). No significant differences were found between markets with trained (n = 6) or untrained (n = 32) managers (all p > 0.05), indicating that infrastructure alone did not explain observed differences in biosecurity scores. In contrast, significant differences were observed in implemented biosecurity practices. Markets with trained managers were more likely to apply measures including segregation of animals, prevention of mixing in pens and nose-to-nose contact, the use of quarantine or isolation areas, C&D of animal holdings, proper waste management, and record-keeping of animal movements (all p < 0.05) ([Table 8](#)).

4. Discussion

While risks associated with ruminant trade in LAMs are increasingly documented in Africa and Asia, our target area remains largely overlooked [[10,11,34,38,41](#)]. This study provides a comprehensive assessment of biosecurity practices in LAMs in Armenia, Azerbaijan, Georgia, and Moldova, highlighting structural vulnerabilities, operational gaps, and opportunities for risk mitigation. Overall, our findings indicate that

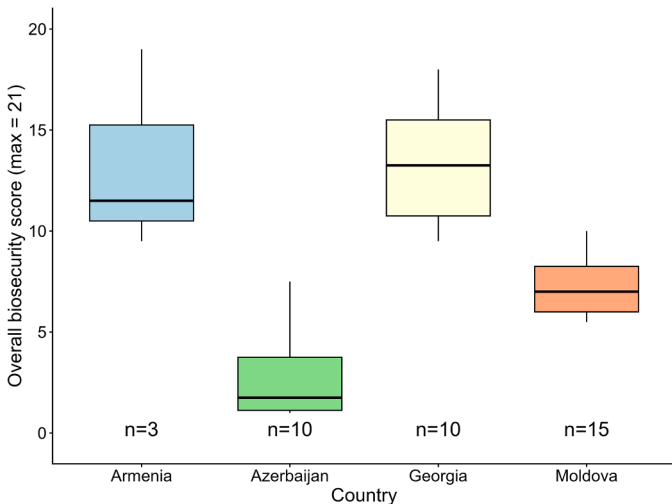


Fig. 2. Distribution of overall market-level biosecurity scores by country (n = 38 markets). Boxes represent the interquartile range, horizontal lines indicate the median, and whiskers extend to the minimum and maximum values excluding outliers. Scores range from 0 to 21, with higher scores indicating better biosecurity implementation.

Table 8

Comparison of market characteristics, infrastructure, and biosecurity practices in markets with trained vs. untrained managers. Values represent the proportion of markets within each group (trained, n = 6; untrained, n = 32) in each category.

		Trained (n = 6)	Untrained (n = 32)	P-value (Fisher)
Manager characteristics				
Livestock exposure	No	17 (1/6)	31(10/32)	0.65
	Yes	83 (5/6)	69 (22/32)	
Market characteristics and infrastructure				
Market type	Primary	83 (5/6)	75 (24/32)	1.00
	Secondary	17 (1/6)	22 (7/32)	
	Terminal	0 (0/6)	3 (1/32)	
Operation frequency	One day per week	67 (4/6)	81 (26/32)	0.58
	More than one day per week	33 (2/6)	19 (6/32)	
Setup	Both indoor and outdoor areas	100 (6/6)	50 (16/32)	0.07
	Fully outdoors	0 (0/6)	50 (16/32)	
Area	< 5000 m ²	33 (2/6)	56 (18/32)	0.62
	5000-20000m ²	33 (2/6)	22 (7/32)	
	>20000m ²	33 (2/6)	22 (7/32)	
Access control (i.e., fencing, gates)	No	17 (1/6)	3 (1/32)	0.57
	Yes	83 (5/6)	97 (31/32)	
Ruminant species	Cattle only	33 (2/6)	12 (4/32)	0.27
	SR only	0 (0/6)	0 (0/6)	
Non-ruminant species	Both cattle and SR	67 (4/6)	88 (28/32)	0.57
	No	17 (1/6)	12 (4/32)	
	Yes	83 (5/6)	88 (28/32)	
Biosecurity/hygiene infrastructure				
Loading/unloading area	No	17 (1/6)	22 (7/32)	1.00
	Yes, but not always used	16 (1/6)	19 (6/32)	
Laboratory testing section	Yes	67 (4/6)	59 (19/32)	0.62
	No	67 (4/6)	75 (24/32)	
	Yes, but not always used	16 (1/6)	13 (4/32)	
Cleaning and disinfection area for transport vehicles	Yes	17 (1/6)	13 (4/32)	0.003
	No	50 (3/6)	50 (16/32)	
	Yes, but not always used	0 (0/6)	47 (15/32)	
Footwear disinfection -visitors	Yes	50 (3/6)	3 (1/32)	0.007
	No	33 (2/6)	78 (25/32)	
	Yes, but not always used	34 (2/6)	22 (7/32)	
Footwear disinfection -staff	Yes	33 (2/6)	0 (0/32)	0.03
	No	33 (2/6)	75 (24/32)	
	Yes, but not always used	50 (3/6)	16 (5/32)	
Handwashing facilities	Yes	17 (1/6)	9 (3/32)	0.0005
	No	0 (0/6)	56 (18/32)	
	Yes, but not always used	0 (0/6)	22 (7/32)	
	Yes	100 (6/6)	22 (7/32)	
Biosecurity practices				
Segregation	None	0 (0/6)	38 (12/32)	0.001
	Partial	0 (0/6)	44 (14/32)	
	Complete	100 (6/6)	19 (6/32)	
Quarantine/isolation area	No	33 (2/6)	84 (27/32)	0.01
	Yes	67 (4/6)	16 (5/32)	
Cleaning and disinfection of animal holdings	No effective cleaning or disinfection	33 (2/6)	44 (14/32)	0.12
	Cleaning without disinfection or inconsistent practices	50 (3/6)	50 (16/32)	
	Cleaning and disinfection systematically applied	17 (1/6)	6 (2/32)	
	No cleaning	17 (1/6)	19 (6/32)	
Cleaning methods	Only dry cleaning	33 (2/6)	25 (8/32)	0.76
	Only wet cleaning	0 (0/6)	0 (0/32)	

Table 8 (continued)

		Trained (n = 6)	Untrained (n = 32)	P-value (Fisher)
Disinfection of animal holdings	Both dry and wet cleaning	50 (3/6)	56 (18/32)	0.008
	No disinfection	0 (0/6)	53 (17/32)	
	Not always (e.g., only during outbreaks)	33 (2/6)	28 (9/32)	
Waste management	Yes, always	67 (4/6)	19 (6/32)	0.0002
	None	0 (0/6)	34 (11/32)	
	Only liquid	0 (0/6)	0 (0/32)	
	Only solid	0 (0/6)	47 (15/32)	
Pest control	Both liquid and solid	100 (6/6)	19 (6/32)	0.07
	No	0 (0/6)	38 (12/32)	
	Yes	100 (6/6)	63 (20/32)	
Record-keeping animal movements	No	17 (1/6)	75 (24/32)	0.004
	Not always	0 (0/6)	9 (3/32)	
	Yes	83 (5/6)	16 (5/32)	
Record-keeping stakeholder movements	No	67 (4/6)	81 (26/32)	0.38
	Not always	0 (0/6)	3 (1/32)	
	Yes	33 (2/6)	16 (5/32)	
Sharing of transport vehicles	No	33 (2/6)	9 (3/32)	0.85
	Yes	67 (4/6)	91 (29/32)	
Inspection of animals at entry	No	0 (0/6)	6 (2/32)	0.36
	Not always/not all animals	17 (1/6)	44 (14/32)	
	Yes	83 (5/6)	50 (16/32)	
Documents checked at entry	No	17 (1/6)	34 (11/32)	0.06
	Yes	83 (5/6)	66 (21/32)	
Display of awareness materials	No	50 (3/6)	78 (25/32)	0.41
	Yes	50 (3/6)	22 (7/32)	

Data source: market manager interviews.

LAMs in this region operate within a context of structural and organizational constraints that increase the risk of pathogen introduction and spread through market operations. Despite these challenges, markets with trained managers consistently demonstrated significantly higher biosecurity scores, suggesting that training is a critical determinant of effective biosecurity implementation.

An important outcome of this work is the development and piloting of a structured survey-based assessment tool for biosecurity in live animal markets. The tool was iteratively refined through piloting at six markets in Türkiye and Armenia prior to full deployment, and subsequently applied across 41 markets in four countries, demonstrating its feasibility and practical applicability in diverse field settings. While formal psychometric validation and systematic comparison against independent observational data were beyond the scope of this study, the piloting process and cross-country application provide a foundation for future refinement and validation. As such, this tool provides a practical basis for future comparative and longitudinal biosecurity assessments in live animal markets.

4.1. Structural and operational vulnerabilities

LAMs are dynamic environments, characterized by intense animal movement, frequent mixing of animals from different origins, species, and health status, and interactions between multiple stakeholders. From an epidemiological perspective, LAMs can be understood as amplifiers of disease risk through a sequential pathway of aggregation, contact amplification, and redistribution [19,25,52].

Prior to market entry, animals originating from multiple herds and epidemiological units with heterogeneous health status are aggregated, often with limited pre-entry filtering [38]. At the market, this aggregation is compounded by high contact rates through direct animal mixing, nose-to-nose contact, and indirect transmission pathways involving contaminated surfaces, transport vehicles, equipment, and

people, with environmental persistence further sustaining transmission [10,11,53]. Following market activities, traded animals are frequently redistributed to multiple farms, fattening operations, or other markets rather than being sent directly to slaughter, often without post-market quarantine or isolation. This facilitates the introduction of pathogens into new herds [20,26,28]. In this sense, LAMs function not merely as points of exchange but as multipliers of disease risk across production systems [25,52].

In Armenia, as reported in 3.2.5. the majority of sellers spontaneously reported in open-ended responses that they “only bring healthy animals” to market, relying on superficial assessment rather than objective indicators or documentation, which risks overlooking incubating, asymptomatic, or subclinical infections. Interestingly, the same users evaluated the health status of purchased animals through certificates or veterinary checks, suggesting a dynamic in which incoming animals are viewed as potential threats, but market-exposed animals are not. This discrepancy may reflect limited awareness of transmission pathways and an underestimation of the role that LAMs have in pathogen dissemination.

The conditions at LAMs are particularly relevant for ruminants susceptible to highly contagious diseases such as foot-and-mouth disease [10,11,3,39,40,47], lumpy skin disease [29,36,51,6], and peste des petits ruminants [10,35,54]. For ruminants in particular, the internal layout of LAMs poses a serious biosecurity risk. In most markets visited, ruminants from different owners were held in shared pens or open spaces with limited barriers to direct contact, which are primary transmission routes for many ruminant pathogens. Although improvements to limit contact are possible, complete segregation is inherently difficult to achieve in LAMs due to their dynamic nature and limited space. During market operations, animals frequently switch hands and move from pen to pen, especially when stakeholders are both buying and selling, which inevitably results in mixing. Given this, the fact that many LAMs surveyed did enforce some segregation, whether by species, age group, or owner, is positive, even if only partial.

Given that live animals represent the highest risk in disease transmission pathways, efforts to minimize contact remain important, but should be considered as part of a broader risk mitigation strategy. Perhaps the most critical point is controlling the entry of animals into the market, to ensure that only healthy animals are allowed in. Although market staff frequently reported strict procedures, the reality on the ground suggests these controls are far more limited in practice. The sheer volume of animals and people moving through the markets makes it operationally difficult to inspect every animal or verify all documentation, especially during peak activity. Even when verifications were theoretically in place, the effectiveness of screening was further weakened by incomplete National Animal Identification and Traceability Systems (NAITS) [2]. In some settings, animals with clinical signs or missing paperwork were expected to be denied entry, yet enforcement varied widely and was sometimes absent. Free-roaming animals entering premises further undermined these controls. Without thorough screening at market gates, the effectiveness of all downstream biosecurity measures, even if fully implemented, is significantly diminished.

Attention must also shift to measures such as C&D of animal holdings, improved transport biosecurity, and personal hygiene. Although C&D of premises was reported in some markets, actual protocols were often insufficient, with disinfection only being done in the case of outbreaks, for example. Handwashing was rarely done between animal handling and eating, or during self-inspection of multiple animals. Inadequate C&D and personal hygiene increase the risk of cross-contamination between successive batches of animals and facilitate indirect transmission via shared equipment, surfaces, or personnel, but also expose potential for zoonotic transmission [33,43,55,8]. Unrestricted movement of stakeholders within markets further complicates hygiene control. As expected in LAMs, sellers, buyers, and other actors circulate freely to inspect and negotiate animals. Such circulation is

inherently difficult to restrict, however, because it often occurs in the absence of effective mitigating measures (i.e., screening at entry, adequate C&D of animal holding areas), and it increases the likelihood of pathogen spread through human vectors.

In high-throughput settings, partial or inconsistent implementation of biosecurity measures is therefore unlikely to sufficiently disrupt transmission pathways.

Despite our study's focus on ruminants, it is important to note that other species, including pigs, poultry, and rabbits, were also present at many LAMs across all countries, further complicating internal biosecurity as cross-species contamination cannot be excluded. In Georgia, Moldova, and Azerbaijan, LAMs also had sellers with fresh produce or animal products, due to the mixed nature of their markets, raising potential concerns for food safety.

Combined, these findings show that many LAMs in the region lack sufficient biosecurity to mitigate the risks posed by intense animal traffic, intricate stakeholder interactions, and structural weaknesses. Similar results have been shown in other countries, especially in informal or resource-limited market settings [1,32,8,41,45].

Beyond animal health, several of the observed biosecurity and hygiene gaps have potential implications for human exposure in market settings, underscoring the relevance of these findings within a One Health framework. Market activities involve close contact between animals, traders, butchers, visitors, and slaughter personnel, and gaps in hygiene infrastructure (e.g., handwashing, waste management, slaughter practices) may pose risks to human health, particularly for zoonotic diseases such as brucellosis. Where on-site slaughter was observed (exclusively in a subset of Azerbaijani markets) conditions varied considerably. In the most concerning case, slaughter occurred in an open, non-designated space with unrestricted public access and no required hygiene measures, creating direct exposure pathways for market visitors and traders in proximity to live animals. Even in markets with designated slaughter areas, PPE use was inconsistent and biological waste management was largely absent. These conditions are particularly relevant given the documented burden of brucellosis in Armenia, Azerbaijan, and Georgia [31,48,50] and underscore the One Health dimensions of market biosecurity beyond animal-to-animal transmission.

Although the level of implementation is variable, it is important to note that biosecurity is increasingly embedded in national legislation throughout the study countries. In Georgia, veterinary and sanitary inspections at LAMs are regulated by the Food Products/Animal Feed Safety, Veterinary and Plant Protection Code (2014 amended through 2021), together with the Government Resolution No. 417: Technical Regulation on the Rules for the Sale of Food and Animals at Agrarian Markets (2013) [21,22]. These mandate veterinary inspection hygiene measures, animal health requirements and species segregation at markets. In Azerbaijan, veterinary-sanitary norms approved by the Food Safety Agency in 2024 set formal requirements for segregation, controlled entry and exit, disinfection, and on-site veterinary supervision [17]. Following recent foot-and-mouth disease outbreaks, markets were temporarily closed and permitted to reopen only after inspection and verified compliance with these standards, indicating that enforcement has become more substantial, although it remains dependent on market-level capacity and infrastructure. Government Resolution No. 1829-N: REQUIREMENTS FOR AGRICULTURAL LIVESTOCK MARKETS (2024) [23] in Armenia similarly mandates that all LAMs operate under state veterinary supervision and adhere to biosecurity and infrastructure standards, such as having controlled entry, isolation areas, disinfection facilities, and mandatory veterinary inspections. In Moldova, LAMs are subordinated to local administration with limited funding at village and district levels. Markets operate under the oversight of the National Agency for Food Safety and general veterinary and sanitary regulations, but there are no market-specific norms, and compliance largely depends on the capacity of local authorities. The recent incorporation of these measures into a legal framework is a significant step towards better biosecurity in LAMs in the country, but legislation alone is insufficient to

guarantee consistent implementation and compliance. Taken together, these regulatory developments provide an essential policy framework, but do not necessarily address the practical challenges of implementation at the market level. This underscores the need to focus on training, awareness, and stakeholder engagement as key levers for translating formal requirements into effective biosecurity practices.

4.2. The role of training in improving biosecurity, opportunities for stakeholder engagement, and recommended interventions

From an implementation perspective, the identified gaps in biosecurity differ markedly in terms of feasibility and resource requirements. Some measures with potentially high impact, such as improving entry control, limiting animal mixing, reducing nose-to-nose contact, and promoting post-market isolation of traded animals, could be strengthened through training, awareness, and procedural or behavioral changes with relatively limited resource investment. In contrast, other measures, particularly those related to market infrastructure, waste management, and permanent cleaning and disinfection facilities, would require more substantial structural investment. Sustainably addressing market-level biosecurity will therefore require a combination of both types of interventions, including market design and animal movement governance.

Despite this, stakeholders identified priority biosecurity measures within LAMs. As described in 3.2.5, stakeholders consistently identified practical, interpersonal approaches as preferred means of improving biosecurity. The emphasis among managers on institutional support and co-developed strategies, particularly in Armenia and Moldova, underscores that training programs will only be effective if embedded within broader institutional frameworks. Importantly, stakeholders themselves recognized these systemic limitations, highlighting that training alone will not suffice without institutional support, a finding that should inform the design of any future intervention program in the region. As noted by Arede et al. [2], public veterinary systems in countries of the Black Sea basin are often under-resourced, with limited institutional support and aging personnel. Accordingly, lower biosecurity should be seen as a reflection of limited resources and capacities rather than negligence or disengagement.

Our mixed-effects model indicated that the presence of trained market staff was the strongest predictor of higher biosecurity scores, independent of market infrastructure. Markets managed by trained personnel were more likely to implement effective segregation, avoid pen mixing and nose-to-nose contact, utilize quarantine or isolation areas, perform cleaning and disinfection, manage waste, and maintain movement records. Notably, differences in market infrastructure did not explain this effect, highlighting that behavioral and knowledge-based interventions can substantially improve biosecurity even under structural constraints. This underscores the potential for training programs to be a cost-effective, scalable intervention in regions with limited resources.

Our findings suggest that the following interventions should be prioritized according to their feasibility and expected impact:

- Targeted training programs for market managers and staff, focused on practical implementation of segregation, C&D, quarantine, and basic documentation and record-keeping.
- Enhanced awareness and risk communication, including simple visual guidelines (posters, signage), individual advice, and structured interactions with veterinarians and local authorities, emphasizing disease (particularly asymptomatic) transmission and promoting objective health checks over self-assessment.
- Gradual infrastructural improvements, such as constructing concrete or washable floors, dedicated pens to prevent nose-to-nose contact, isolation areas, C&D facilities, and handwashing stations, which are essential to enable consistent implementation of biosecurity measures.
- Formalization and supervision of markets, ensuring consistent entry control, documentation verification, and standardized biosecurity procedures, while presenting formal markets as safer trade venues to encourage users to move away from informal or online markets where biosecurity cannot be guaranteed.
- Establishment of clear post-purchase disease reporting protocols, including accessible notification channels for buyers to report clinical signs observed in newly acquired animals, and defined responsibilities for veterinary follow-up.
- Vehicle hygiene requirements as a condition of market access, including minimum C&D standards for transport vehicles entering market premises, supported by designated washdown facilities where infrastructure permits.

Importantly, stakeholders recognized these needs and highlighted the importance of co-developing context-specific strategies with local authorities, veterinary services, and cooperatives, emphasizing that training alone will not suffice without institutional support.

While these insights provide important levers for intervention design, they should be interpreted in light of the methodological limitations of this study.

4.3. Study limitations

This study has several limitations. The number of surveyed markets and users varied considerably between countries, affecting cross-country comparability and overall representativeness of the findings. In Armenia and Azerbaijan, all officially operating LAMs were included, but both countries have relatively few markets. In Moldova, user-level data were limited due to strong seasonal fluctuations in ruminant trade, with only four ruminant sellers identified and surveyed by CFPs. This very small sample size constrains the robustness of the user-level analyses and limits the conclusions that can be drawn for this country. In Georgia and Moldova, markets were selected based on convenience sampling, as were most users interviewed across countries, reflecting the practical constraints of engaging stakeholders in active market settings. Additionally, market participants were often wary of discussing their trade activities and biosecurity, which may have influenced responses.

The small number of markets with trained managers ($n = 6$) further limits the precision of estimates for this subgroup. To assess robustness, we conducted leave-one-country-out and leave-one-trained-manager-out sensitivity analyses, group-level influence diagnostics (Cook's distance, DFBETAS), and bootstrapped and profile-likelihood confidence intervals for the training coefficient. The effect remained positive and statistically significant when Azerbaijan, Georgia, or Moldova were excluded individually (β range: 4.5–7.5, all $p < 0.025$) and when any of the five trained Georgian markets were excluded individually (β range: 4.2–5.0, all $p < 0.007$). Excluding Armenia, or its single trained market, attenuated the estimate ($\beta = 1.58$ –2.47, n.s.), reflecting the small number of trained markets available outside Georgia rather than a specific data-quality concern. Importantly, bootstrapped (1000 replicates) and profile-likelihood 95% confidence intervals for the training coefficient excluded zero in all analyses (1.6–7.8 and 2.1–8.2, respectively), and 100% of bootstrap replicates were positive, supporting the robustness of the direction and significance of this association despite the limited sample size. Similarly, inspection of predictor distributions revealed zero count for several predictors within individual countries. For example, no trained managers were identified in Azerbaijan or Moldova, and all markets in these countries included non-ruminant species. While these zero counts would be problematic in a country-stratified analysis, the mixed-effects model estimates fixed effects across all 38 markets jointly, with country included as a random intercept rather than a fixed factor. This means the model does not attempt to estimate country-specific slopes, partially mitigating concerns about zero counts within countries. Nevertheless, these distributional imbalances represent a structural limitation of the dataset, and findings should be interpreted

accordingly.

Additionally, this study relies on self-reported data from market stakeholders. While CFPs were trained to perform biosecurity assessments through semi-structured interviews to mitigate recall and social desirability bias, these biases are difficult to eliminate, particularly for questions about biosecurity compliance, such as C&D practices. Triangulation with field observations and photographic documentation helped contextualize reported practices but uncertainty remains. Additionally, while on-site slaughter practices were captured in the survey, the absence of a dedicated question on reasons for slaughter represents a gap in the current survey design; future iterations should distinguish between planned commercial slaughter and emergency or welfare-driven slaughter events, as these carry distinct biosecurity implications.

Informal trade and off-market transactions, organized via social networks, personal contacts, or online platforms, play an increasingly important role in the region's livestock trade as reported by CFPs and market stakeholders. These channels are especially relevant when outbreaks trigger market closures, as trade often shifts from formal to informal settings. Evidence from CFPs suggests significant heterogeneity in how informal trade operates. In Georgia, a substantial portion of ruminant trade occurs through informal markets, often in parallel to official LAMs. While we targeted two of these sites during fieldwork, they were not included in the present study due to limited information on their operational characteristics. Sanitary measures, however, were reported to be limited and generally poorer than in official markets. In Armenia, some of the markets included in this study lacked formal registration but were organized by identified operators and subject to official veterinary supervision, reflecting a transitional situation that differs from fully informal or illegal markets.

This study could not systematically assess the scale and implications for biosecurity of these trading channels as they are unregulated and undocumented.

While this study provides a cross-sectional view of market conditions, longitudinal research through repeated assessments would be required to better understand the consistency of biosecurity measure implementation over time, the impacts of policy, and evolving behavioral patterns.

5. Conclusion

This study highlights considerable limitations in biosecurity implementation across LAMs. Limited infrastructure, inconsistent enforcement, partial segregation, and inadequate sanitation practices contribute to observed gaps, while high volumes of ruminant trade, limited on-farm quarantine, informal trade channels, and widespread mixing of animals throughout the supply chain further exacerbate risks. From a policy perspective, the regulatory frameworks needed to address these gaps are increasingly in place across the region. Armenia, Azerbaijan, and Georgia have all recently introduced legislation mandating biosecurity standards in LAMs, including controlled entry, disinfection facilities, and veterinary supervision. However, legislation alone is insufficient if the practical conditions for compliance do not exist at the market level. The gaps documented in this study, earthen floors that cannot be effectively disinfected, absent C&D facilities, limited veterinary presence, and no formal disease reporting channels, reflect an implementation deficit rather than a regulatory one. Bridging this gap will require targeted investment in market infrastructure, including concrete yards and metal fencing, water access for animal holding area and vehicle washdown, and formal communication channels for reporting notifiable diseases such as foot-and-mouth disease, as well as mechanisms to verify and audit compliance. Despite these challenges, our findings indicate that training of market managers is the most important modifiable factor associated with better biosecurity outcomes. Markets with trained personnel consistently demonstrated improved segregation, cleaning and disinfection, quarantine practices,

and record-keeping, regardless of structural constraints. While infrastructural improvements and institutional support remain critical, targeted training programs and awareness campaigns offer a cost-effective and immediate opportunity to enhance LAM biosecurity. The finding that trained managers consistently achieved better biosecurity outcomes independent of market infrastructure suggests that behavioral and knowledge-based interventions have the potential to substantially improve biosecurity even under structural constraints, a hypothesis that warrants further investigation through prospective intervention studies. Future research should examine the design, delivery, and long-term effectiveness of training programs in LAM settings, including optimal training content, frequency, and target audiences, as well as the conditions under which behavioral change can be sustained without parallel infrastructural investment. Importantly, stakeholders expressed willingness to improve practices and provided concrete suggestions, demonstrating both an awareness of risks and recognition of systemic limitations. Sustained engagement, combining behavioral interventions with gradual infrastructural improvements and formalized market oversight, is essential to strengthen biosecurity and promote safer, more resilient livestock systems across the region. Findings from this study will be shared with relevant authorities to identify (and prioritize) the riskiest LAMs (in terms of biosecurity), the main biosecurity gaps, and, accordingly, inform the design of training, awareness, and support programs aimed at improving biosecurity practices in LAMs. Beyond the empirical findings, the survey tools developed here provide a practical basis for future comparative and longitudinal assessments of biosecurity in live animal markets.

CRedit authorship contribution statement

Sarah Oste: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Formal analysis, Data curation, Conceptualization. **Daniel Beltrán-Alcrudo:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization. **Mark Hovari:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Conceptualization. **Mikayel Haykuni:** Writing – review & editing, Resources, Investigation. **Nicolae Starciuc:** Writing – review & editing, Resources, Investigation. **Alberto Allepuz Palau:** Writing – review & editing, Validation, Supervision, Methodology, Conceptualization.

Ethics approval

This study was approved by the Ethics Committee of the Universitat Autònoma de Barcelona (approval number: UAB-CERec218).

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used Grammarly and ChatGPT 5.2 to correct grammar and syntax. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

Funding

This work was sponsored by the United States Department of Defense, Defense Threat Reduction Agency. The content of the information does not necessarily reflect the position or the policy of the Federal Government of the United States, and no official endorsement should be inferred. The project was implemented by the Food and Agriculture Organization of the United Nations (FAO) with the support of the Universitat Autònoma de Barcelona.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We would like to extend our gratitude to all participating market users and managers for their time. We would also like to thank the Association for Veterinary and Public Health (AVPH) in Georgia, and Elshad Rzayev from Azerbaijan, for their support in the data collection. Our thanks also go to colleagues from Türkiye who supported the piloting of the surveys: Naim Deniz Ayaz, Görkem Cengiz, Gizem Çufaoğlu, and Mehmet Murat Doğan. Finally, we appreciate the support of Dianna Defrenza in improving the clarity and readability of the manuscript.

We would like to acknowledge support and funding provided by the United States DoD DTRA Cooperative Threat Reduction Program: project HDTRA1-19-1-0037, under The Global Framework for the Progressive Control of Transboundary Animal Diseases (GF-TADs).

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.pvmr.2026.100030](https://doi.org/10.1016/j.pvmr.2026.100030).

Data availability

Data will be made available on request.

References

- Adams, L., Gray, G., and Murray, G. (2012). Animal biosecurity in the Mekong: future directions for research and development. Proceedings of an International Workshop Held in Siem Reap, Cambodia, 10–13 August 2010, 45–59. (http://aciir.gov.au/files/node/14481/pr137_animal_biosecurity_in_the_mekong_future_di_10786.pdf).
- Aredé M, Beltrán-Alcrudo D, Aliyev J, Chaligava T, Keskin I, Markosyan T, et al. Examination of critical factors influencing ruminant disease dynamics in the Black Sea Basin. *Front Vet Sci* 2023;10(September):1–12. <https://doi.org/10.3389/fvets.2023.1174560>.
- Avalos A, Durand B, Naranjo J, Maldonado V, Canini L, Zanella G. Analysis of cattle movement networks in Paraguay: Implications for the spread and control of infectious diseases. *PLoS ONE* 2022;17(12 December):1–22. <https://doi.org/10.1371/journal.pone.0278999>.
- Bates D, Mächler M, Bolker B, Walker S. Fitting Linear Mixed-Effects Models Using lme4. *J Stat Softw* 2015;67(1). <https://doi.org/10.18637/jss.v067.i01>.
- Bernard HR. *Research Methods in Anthropology: Qualitative and Quantitative Approaches*. 4th ed. AltaMira Press; 2011.
- Bianchini J, Simons X, Humblet MF, Saegerman C. Lumpy Skin Disease: A Systematic Review of Mode of Transmission, Risk of Emergence and Risk Entry Pathway. *Viruses* 2023;15(8):1–71. <https://doi.org/10.3390/v15081622>.
- Cardenas NC, Sykes AL, Lopes FPN, Machado G. Multiple species animal movements: network properties, disease dynamics and the impact of targeted control actions. *Vet Res* 2022;53(1):14. <https://doi.org/10.1186/s13567-022-01031-2>.
- Chowdhury S, Azziz-Baumgartner E, Kile JC, Hoque MA, Rahman MZ, Hossain ME, et al. Association of biosecurity and hygiene practices with environmental contamination with influenza A viruses in live bird markets, Bangladesh. *Emerg Infect Dis* 2020;26(9):2087–96. <https://doi.org/10.3201/eid2609.191029>.
- Cohen J. *Statistical Power Analysis for the Behavioral Sciences*. Elsevier; 1977. <https://doi.org/10.1016/C2013-0-10517-X>.
- Colenutt C, Brown E, Paton DJ, Mahapatra M, Parida S, Nelson N, et al. Environmental sampling for the detection of foot-and-mouth disease virus and peste des petits ruminants virus in a live goat market, Nepal. *Transbound Emerg Dis* 2022;69(5):3041–6. <https://doi.org/10.1111/tbed.14257>.
- Colenutt C, Shaw A, Esemu SN, Kfusi AJ, Willington Ojong B, Brown E, et al. Detection and genomic characterisation of foot-and-mouth disease virus serotypes circulating in Cameroon using environmental sampling. *Sci Rep* 2025;15(1):2834. <https://doi.org/10.1038/s41598-024-84724-2>.
- European Commission. (2025). *EuSurvey*. (<https://ec.europa.eu/eusurvey/home/welcome>).
- FAO. Developing the sheep value chain in Azerbaijan – Vision 2025. FAO; 2020. <https://doi.org/10.4060/cb0288en>.
- FAO. Smallholders and family farms in Armenia. FAO; 2020. <https://doi.org/10.4060/ca9823en>.
- FAO. Smallholders and family farms in Georgia. FAO; 2020. <https://doi.org/10.4060/ca9822en>.
- FAO. Smallholders and family farms in the Republic of Moldova. FAO; 2020. <https://doi.org/10.4060/ca9836en>.
- Food Safety Agency of the Republic of Azerbaijan. (2024). *Veterinary and Sanitary Standards and Rules for Animal Markets*. Food Safety Agency of the Republic of Azerbaijan. (<https://e-qanun.az/framework/58208>).
- Fox J, Weisberg S. *An R Companion to Applied Regression* (Third). Sage; 2019. (<https://www.john-fox.ca/Companion/>).
- Galindo-González J. Live animal markets: Identifying the origins of emerging infectious diseases. *Curr Opin Environ Sci & Health* 2022;25:100310. <https://doi.org/10.1016/j.coesh.2021.100310>.
- González-Gordon L, Porphyre T, Muwonge A, Nantima N, Ademun R, Ochwo S, et al. Identifying target areas for risk-based surveillance and control of transboundary animal diseases: a seasonal analysis of slaughter and live-trade cattle movements in Uganda. *Sci Rep* 2023;13(1):1–16. <https://doi.org/10.1038/s41598-023-44518-4>.
- Government of Georgia. (2013). *Government Resolution No. 417: Technical Regulation on the Rules for the Sale of Food and Animals at Agrarian Markets*. (<http://www.matsne.gov.ge/ka/document/view/2187664?publication=0>).
- Government of Georgia - Parliament of Georgia. (2014). *Food Products/Animal Feed Safety, Veterinary and Plant Protection Code*. (<https://matsne.gov.ge/en/document/view/1659434?publication=15>).
- Government of the Republic of Armenia. Resolution No. 1829-N: REQUIREMENTS FOR AGRICULTURAL LIVESTOCK MARKETS. Government of the Republic of Armenia; 2024. (<http://www.arlis.am/DocumentView.aspx?DocID=200006>).
- Gubrium JF, Holstein JA, editors. *Handbook of Interview Research: Context and Method*. SAGE Publications; 2001. <https://doi.org/10.4135/9781412973588>.
- Hardstaff JL, Häslér B, Rushton JR. Livestock trade networks for guiding animal health surveillance. *BMC Vet Res* 2015;11(1):1–13. <https://doi.org/10.1186/s12917-015-0354-4>.
- Hasahya E, Thakur K, Dione MM, Kerfua SD, Mugezi I, Lee HS. Analysis of patterns of livestock movements in the Cattle Corridor of Uganda for risk-based surveillance of infectious diseases. *Front Vet Sci* 2023;10. <https://doi.org/10.3389/fvets.2023.1095293>.
- Hennessy DA, Rault A. On systematically insufficient biosecurity actions and policies to manage infectious animal disease. *Ecol Econ* 2023;206(July 2020):107740. <https://doi.org/10.1016/j.ecolecon.2023.107740>.
- Hernández-Jover M, Schembri N, Toribio J-ALML, Holyoake PK. Biosecurity risks associated with current identification practices of producers trading live pigs at livestock sales. *Animal* 2008;2(11):1692–9. <https://doi.org/10.1017/S1751731108003066>.
- Ince ÖB, Çakır S, Dereli MA. Risk analysis of lumpy skin disease in Turkey. *Indian J Anim Res* 2016;50(6):1013–7. <https://doi.org/10.18805/ijar.9370>.
- Kassambara A. (2025). *rstatix: Pipe-Friendly Framework for Basic Statistical Tests*. (<https://github.com/kassambara/rstatix>).
- Kracalik IT, Abdullayev R, Asadov K, Ismayilova R, Baghirova M, Ustun N, et al. Human Brucellosis Trends: Re-emergence and Prospects for Control Using a One Health Approach in Azerbaijan (1983–2009). *Zoonoses Public Health* 2016;63(4):294–302. <https://doi.org/10.1111/zph.12229>.
- Leslie EEC, Geong M, Abdurrahman M, Ward MP, Toribio J-ALML. Live pig markets in eastern Indonesia: Trader characteristics, biosecurity and implications for disease spread. *Acta Trop* 2016;155:95–103. <https://doi.org/10.1016/j.actatropica.2015.12.014>.
- Lin B, Dietrich ML, Senior RA, Wilcove DS. A better classification of wet markets is key to safeguarding human health and biodiversity. *Lancet Planet Health* 2021;5(6):e386–94. [https://doi.org/10.1016/S2542-5196\(21\)00112-1](https://doi.org/10.1016/S2542-5196(21)00112-1).
- Lysholm S, Fischer K, Lindahl JF, Munyeme M, Wensman JI. Seropositivity rates of zoonotic pathogens in small ruminants and associated public health risks at informal urban markets in Zambia. *Acta Trop* 2022;225(October 2021):106217. <https://doi.org/10.1016/j.actatropica.2021.106217>.
- Mdetete DP, Komba E, Seth MD, Misinzio G, Kock R, Jones BA. Review of peste des petits ruminants occurrence and spread in Tanzania. *Animals* 2021;11(6). <https://doi.org/10.3390/ani11061698>.
- Mercier A, Arsevska E, Bournez L, Bronner A, Calavas D, Cauchard J, et al. Spread rate of lumpy skin disease in the Balkans, 2015–2016. *Transbound Emerg Dis* 2018;65(1):240–3. <https://doi.org/10.1111/tbed.12624>.
- Motta P, Garner G, Hövari M, Alexandrov T, Bulut A, Fragou IA, et al. A framework for reviewing livestock disease reporting systems in high-risk areas: assessing performance and perceptions towards foot and mouth disease reporting in the Thrace region of Greece, Bulgaria and Turkey. *Transbound Emerg Dis* 2019;66(3):1268–79. <https://doi.org/10.1111/tbed.13143>.
- Motta P, Porphyre T, Handel IG, Hamman SM, Ngu Ngwa V, Tanya VN, et al. Characterizing Livestock Markets, Primary Diseases, and Key Management Practices Along the Livestock Supply Chain in Cameroon. *Front Vet Sci* 2019;6. <https://doi.org/10.3389/fvets.2019.00101>.
- Munsey A, Mwiine FN, Ochwo S, Velazquez-Salinas L, Ahmed Z, Maree F, et al. Phylogeographic analysis of foot-and-mouth disease virus serotype O dispersal and associated drivers in East Africa. *Mol Ecol* 2021;30(15):3815–25. <https://doi.org/10.1111/mec.15991>.
- Munsey A, Mwiine FN, Ochwo S, Velazquez-Salinas L, Ahmed Z, Rodriguez LL, et al. Ecological and Anthropogenic Spatial Gradients Shape Patterns of Dispersal of Foot-and-Mouth Disease Virus in Uganda. *Pathogens* 2022;11(5):1–11. <https://doi.org/10.3390/pathogens11050524>.

- [41] Mutua EN, Bett BK, Bukachi SA, Estambale BA, Nyamongo IK. From policy to practice: An assessment of biosecurity practices in cattle, sheep and goats production, marketing and slaughter in Baringo County, Kenya. *PLoS ONE* 2022;17(4 April):1–24. <https://doi.org/10.1371/journal.pone.0266449>.
- [42] Mutua F, Dione M. The Context of Application of Biosecurity for Control of African Swine Fever in Smallholder Pig Systems: Current Gaps and Recommendations. *Front Vet Sci* 2021;8(August):1–11. <https://doi.org/10.3389/fvets.2021.689811>.
- [43] Naguib MM, Li R, Ling J, Grace D, Nguyen-Viet H, Lindahl JF. Live and wet markets: Food access versus the risk of disease emergence. *Trends Microbiol* 2021;29(7):573–81. <https://doi.org/10.1016/j.tim.2021.02.007>.
- [44] Nederhof AJ. Methods of coping with social desirability bias: A review. *Eur J Social Psychol* 1985;15(3):263–80. <https://doi.org/10.1002/ejsp.2420150303>.
- [45] Onduso R, Onono JO, Ombui JN. Assessment of structure and performance of cattle markets in western Kenya. *Trop Anim Health Prod* 2020;52(2):725–32. <https://doi.org/10.1007/s11250-019-02062-2>.
- [46] Pinheiro, J., Bates, D., and R. Core Team. (2025). nlme: Linear and Nonlinear Mixed Effects Models. In CRAN: Contributed Packages. <https://doi.org/10.32614/CRAN.package.nlme>.
- [47] Poolkhet C, Kasemsuwan S, Phiphakhavong S, Phouangsouvanh I, Vongxay K, Shin MS, et al. Social network analysis for the assessment of pig, cattle and buffalo movement in Xayabouli, Lao PDR. *PeerJ* 2019;2019(1):1–14. <https://doi.org/10.7717/peerj.6177>.
- [48] Porphyre T, Jackson R, Sauter-Louis C, Ward D, Baghyan G, Stepanyan E. Mapping brucellosis risk in communities in the Republic of Armenia. *Geospatial Health* 2010;5(1):103–18. <https://doi.org/10.4081/gh.2010.191>.
- [49] Posit team. (2025). *RStudio: Integrated Development Environment for R* (2025.9.0.387 Cucumberleaf Sunflower). Posit Software, PBC. (<http://www.posit.co/>).
- [50] Rivas AL, Smith SD, Basiladze V, Chaligava T, Malania L, Burjanadze I, et al. Geotemporal patterns to design cost-effective interventions for zoonotic diseases -the case of brucellosis in the country of Georgia. *Front Vet Sci* 2023;10. <https://doi.org/10.3389/fvets.2023.1270505>.
- [51] Roche X, Rozstalnyy A, TagoPacheco D, Kamata A, Pittiglio C, Beltran Alcrudo D, et al. Introduction and spread of lumpy skin disease in South, East and Southeast Asia. *FAO Animal Production and Health*; 2020. <https://doi.org/10.4060/cb1892en>.
- [52] Ruget A-S, Rossi G, Pepler PT, Beaunée G, Banks CJ, Enright J, et al. Multi-species temporal network of livestock movements for disease spread. *Appl Netw Sci* 2021;6(1):15. <https://doi.org/10.1007/s41109-021-00354-x>.
- [53] Scharzenberger S, Humphreys JM, Rigney C, Freifeld A, Stenfeldt C, Arzt J. Epidemiologic consequences of preclinical transmission of foot-and-mouth disease virus in cattle. *Front Vet Sci* 2025;12:1651091. <https://doi.org/10.3389/fvets.2025.1651091>.
- [54] Sherman DM. The spread of pathogens through trade in small ruminants and their products. *OIE Rev Sci Et Tech* 2011;30(1):207–17. <https://doi.org/10.20506/rst.30.1.2036>.
- [55] Soon JM, Abdul Wahab IR. On-site hygiene and biosecurity assessment: A new tool to assess live bird stalls in wet markets. *Food Control* 2021;127:108108. <https://doi.org/10.1016/j.foodcont.2021.108108>.
- [56] Venables WN, Ripley BD. *Modern Applied Statistics with S* (Fourth). Springer; 2002. (<http://www.stats.ox.ac.uk/pub/MASS4>).
- [57] WOA. (2022). *Terrestrial Animal Health Code: I* (Thirtieth). (<https://rr-africa.woah.org/en/news/new-oie-terrestrial-codes-available-for-download-in-pdf-2021/>).
- [58] Zeileis A. Econometric Computing with HC and HAC Covariance Matrix Estimators. *J Stat Softw* 2004;11(10). <https://doi.org/10.18637/jss.v011.i10>.
- [59] Zeileis A, Hothorn T. Diagnostic checking in regression relationships. *R N* 2002;2(3):7–10. (<https://journal.r-project.org/articles/RN-2002-018/>).
- [60] Zeileis A, Köll S, Graham N. Various Versatile Variances: An Object-Oriented Implementation of Clustered Covariances in R. *J Stat Softw* 2020;95(1). <https://doi.org/10.18637/jss.v095.i01>.
- [61] Dube AK, Ozkan B. Analysis of the Effects of Livestock Market Participation on Food Security and Welfare of Smallholder Farmers in Ethiopia. *New Medit* 2022;21(1). <https://doi.org/10.30682/nm2201g>.
- [62] Kihui EN, Amuakwa-Mensah F. Improving access to livestock markets for sustainable rangeland management. *ZEF Discussion Papers on Development Policy* No. 45. 215, Center for Development Research (ZEF). University of Bonn; 2016. <https://doi.org/10.22004/ag.econ.235107>.
- [64] Melesse MB, Tirra AN, Homann-Kee Tui S, Van Rooyen AF, Hauser M. Production decisions and food security outcomes of smallholder's livestock market participation: empirical evidence from Zimbabwe. *Front. Sustain. Food Syst.* 2023;7:1222509. <https://doi.org/10.3389/fsufs.2023.1222509>.
- [65] Valerio VC, Walther OJ, Eilittä M, Cissé B, Muneeppeerakul R, Kiker GA. Network analysis of regional livestock trade in West Africa. *PLoS One* 2020;15(5):e0232681. <https://doi.org/10.1371/journal.pone.0232681>.
- [66] Yitayew A, Yigezu YA, Kassie GT, Deneke TT, Haile A, Hassen H, Rischkowsky B. Identification of strategies to improve goat marketing in the lowlands of Ethiopia: a hedonic price analysis. *Applied Economics* 2019;51(1):61–75. <https://doi.org/10.1080/00036846.2018.1490693>.
- [67] Yitayew A., Kassie G.T., Yigezu Y.A., Market participation and pastoral welfare in drought-prone areas: A dose-response analysis, *Economic Analysis and Policy*, Volume 80, 2023, Pages 1415-1429, ISSN 0313-5926, <https://doi.org/10.1016/j.eap.2023.10.030>.