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# Characterization of mixed livestock systems applied by small-scale breeders in the high Andean region of Ayacucho, Peru

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Mixed livestock production is a widespread practice among small breeders in many parts of the world. Describing and characterizing these farms is a valuable approach, as it makes it possible to design targeted strategies suited to the wide diversity of production systems present in the region. This research aimed to characterize the mixed livestock systems of small-scale breeders in the high Andean region of Ayacucho, Peru. A total of 175 farms were selected for the research, based on the data obtained from the Instituto Nacional de Innovación Agraria. The information was first examined descriptively using frequency and percentage tables, after which a multiple correspondence analysis (MCA) and a hierarchical cluster analysis (HCA) were carried out. For 93.71% of breeders, animals constituted the primary source of income: cattle provided milk and dairy products, sheep were kept for lamb sales, alpacas supplied fiber and meat, and llamas were raised for meat. Grazing was practiced predominantly under continuous systems (57.71%), with rotational grazing used to a lesser extent (26.86%). Exotic breeds had been incorporated into both cattle (71.05%) and sheep (61.97%). Milking and shearing were performed manually. The main limitations identified in the study regions included the absence of extension services (62.87%), inadequate veterinary assistance (79.43%), scarce irrigation water (55.17%), and weak or nonexistent breeding programs. Three breeder categories were defined: Group 1 comprises breeders operating on small and large non-irrigated landholdings; Group 2 includes breeders with extensive land; and Group 3 encompasses breeders with medium-sized landholdings. These factors included farm size, pasture characteristics, and livestock management practices, which collectively shaped the classification of breeders. These findings reveal that, in the Peruvian Andes, three distinct livestock farm groups were identified on the basis of management practices and resource availability; families typically rely on mixed livestock systems as a key economic lifeline but face limitations throughout the production chain. This breeder classification will serve as the basis for designing specific interventions tailored to the strengths and particular needs of each group.

KEYWORDS
**alpaca, cattle, characterization, high Andean livestock, llama, mixed livestock, sheep**

# Introduction

High Andean livestock ranching plays a crucial role in the economy and in sustaining the livelihoods of peasant communities that occupy extensive areas of the South American Andes at elevations over 3,400 m above sea level (Aranibar et al., 2024). Livestock production in these high Andean zones includes the rearing of alpacas, llamas, sheep, and cattle, all of which confront substantial difficulties stemming from the harsh climatic and geographic conditions of the Andes (Añasco, 2024). In addition, these animals serve as a form of “cash reserve” within the livelihood strategies of millions of smallholder breeders (Randolph et al., 2007; Assefa et al., 2024).

Peru is the world’s main producer of alpacas, with an estimated population of 4,545,820 animals, and the second-largest producer of llamas, with 1,050,004 animals. The Ayacucho region accounts for 7% of the national alpaca and llama population. Peru also holds 5,910,220 heads of cattle and 11,100,080 sheep, of which Ayacucho holds 8% and 5.5%, respectively (MIDAGRI, 2024). Most of the cattle, sheep, alpacas, and llamas are owned by peasant communities and small-scale breeders, who manage them according to their own communal systems, often facing limitations in fodder and water availability. Within the total sheep and cattle population, Creole cattle make up the larger proportion (Torres et al., 2015; Aguilar et al., 2014; Mamani et al., 2021).

Forty percent of the gross value of agricultural production comes from the livestock sector. It is therefore essential to prioritize and direct efforts toward the production chains of cattle, sheep, alpacas, and llamas, with particular emphasis on the small and medium-scale holdings, which are often living in poverty and extreme poverty (MIDAGRI, 2017). In the high Andean regions of Peru, traditional mixed livestock of cattle, sheep, and camelids predominates, where natural pastures and crop residues represent the main feed resources (Gómez-Urviola et al., 2016).

Despite their large populations, their remarkable capacity to adapt to local agro-ecological conditions, and their important social functions, these species have received little attention from development programs and the relevant authorities (Laouadi et al., 2018). The productivity of cattle, sheep, and camelids remains very low, constrained by a range of social, cultural, and technical factors, to such an extent that it fails to satisfy local demand (Assefa et al., 2024). Consequently, it is crucial to optimize the production process to maximize farm productivity (Angón et al., 2017). For this, it is essential to start with a detailed characterization of the production systems and targeted studies of the production process.

In Peru, there is a lack of studies and information on farm typologies that manage mixed breeding of high Andean livestock, where demographic, social, cultural, productive, and commercial factors are analyzed. Knowing these factors is important, as they affect the dynamics of production processes, and market performance can be described and analyzed (Nampanzira et al., 2015; Gómez-Urviola et al., 2016). To develop a comprehensive program for animal genetic improvement, it is crucial to conduct studies that characterize these production systems; to identify, evaluate, select, and conserve animals through gene banks; and to prevent the ongoing erosion of these resistant genes (Torres et al., 2015).

A profound understanding of the characteristics and classification of livestock production systems is a fundamental first step for formulating local development policies in the livestock sector (Ruíz et al., 2019). This knowledge underpins the creation of strategies that encompass genetic improvement programs, more efficient production processes, the development of technical assistance services, and the transfer and adoption of innovation and technology (Hammond et al., 2020; Sarker et al., 2021). Production units that implement sound management practices are distinguished by their productive efficiency, demonstrating that the species are resilient to challenges and acute environmental changes, even in the face of variability among breeders (Mena et al., 2016; Koluman and Silanikove, 2018).

The heterogeneity of farms, in addition to social and cultural factors, is directly influenced by economic and agro-ecological factors (climate, ecosystem, land, and biodiversity), where natural resources are dispersed. This availability of resources allowed human settlement and socioeconomic articulations, attributed to the variability of management in productive processes developed by each producer (Torres, 2001; Fonseca-Carreño et al., 2019).

The characterization of mixed breeding typologies provides key information for livestock and rural development, as it helps to interpret the diversity of livestock production systems within a given region (Alvarez et al., 2018; Kumar et al., 2019). At present, various methods are applied to establish typologies of livestock systems, with multivariate statistical techniques (multivariate analysis) generally considered the most robust (Pacini et al., 2014). Mixed livestock is presented as an option to tackle many of the sustainability issues confronting contemporary agriculture. Yet this crucial activity has been largely overlooked to date (Martin et al., 2020). In response, this study aimed to characterize the mixed livestock systems of small-scale breeders in the high Andean region of Ayacucho, Peru.

# Materials and methods

## Study area

This research formed part of a survey conducted by the Instituto Nacional de Innovación Agraria (INIA) to characterize the production systems for cattle, sheep, and camelids in the Ayacucho region. Cattle were raised at altitudes between 3,200 and 4,200 m a.s.l., sheep between 3,800 and 4,300 m a.s.l., and camelids between 4,000 and 4,700 m a.s.l. Guinea pigs, hens, goats, and pigs were mainly observed in areas where cattle and sheep were present. The ecosystems in these zones are defined by extensive arid areas, steppes, mountains, cliffs, and inter-Andean and high Andean enclaves, which support grassland formations such as grasslands, wetlands, steppes, and both cultivated and natural pastures used for cattle grazing.

## Survey model

### Data selection

Between April and June 2025, a random survey was conducted among cattle, sheep, and camelid production units. The

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TABLE 1 List of qualitative variables for the MCA.

| Variable | Code | Modalities |
|---|---|---|
| Housing material | Housing | Noble material |
| | | Adobe |
| | | Stone |
| Power source | Energy_source | Electrical network |
| | | Panel |
| | | It does not count |
| Source of income | Economy_source | Agriculture |
| | | Livestock |
| | | Trade |
| | | Temporary labor |
| | | Other |
| Extension of the property | Land_extension | <2 Ha |
| | | 3–5 Ha |
| | | 6–10 Ha |
| | | >10 Ha |
| Irrigation system | Irrigation_system | Gravity |
| | | Sprinkling |
| | | Drip |
| | | Does not use irrigation |
| Grazing system | Grazing_system | Continuous |
| | | Rotational |
| | | Seasonal |
| | | Others |
| Type of grass consumed | Type_grass | Natural |
| | | Cultivated |
| | | Natural + cultivated |
| A grazing ground | Grazing_land | Own |
| | | Communal |
| | | Rental |
| | | Own + communal |
| | | Own + communal + rental |
| | | Own + rental |
| | | Communal + rental |
| Purchase of breeding stock | Origin_male | Own |
| | | Neighbor |
| | | Region |
| | | National |
| | | Exchange |
| | | Outside the country |
| Veterinary care | Veterinary_care | State professional |
| | | Private professional |
| | | State technician |
| | | Private technician |
| | | Promoter |
| | | The owner |
| | | Does not perform |

(*Continued*)

TABLE 1 Continued

questionnaires used in the survey were designed specifically for cattle, sheep, and camelids, and all three followed the same structure and were approved following a field pilot test and review by INIA experts. Among the camelids, alpacas and llamas were included. Using the finite population formula, with a 95% confidence level (1.96) and a 10% margin of error, interviews were conducted with cattle (n = 96), sheep (n = 96), and camelid (n = 94) breeders.

For the purposes of this study, access was requested to the database for INIA project CUI No. 2491159, and consent was obtained to use the database. Of the 286 interviews collected, 175 were included, based on two exclusion criteria used by Ayala et al. (2024). First, farms were required to raise cattle, sheep, alpacas, and llamas; any farm lacking at least one of these species was excluded. Second, interviews containing incomplete data or information not pertinent to the study were removed.

The information gathered covered four main components: 1) sociodemographic, 2) socioeconomic, 3) productive, and 4) marketing. Demographic variables included age, sex, type of housing, language, and access to household services. Socioeconomic aspects encompassed sources of income, time devoted to caregiving, and land availability. Productive aspects included feeding, facilities, reproduction, genetics, shearing, milking, and animal health. Finally, marketing factors involved product price, frequency of supply, and the type of marketing channel used.

## Statistical analysis

### Descriptive analysis

The data were entered and analyzed using R statistical software, version 4.3.1. In the initial stage of the analysis, the collected information was examined descriptively through frequency and percentage tables, and quantitative variables were evaluated using measures of central tendency and dispersion.

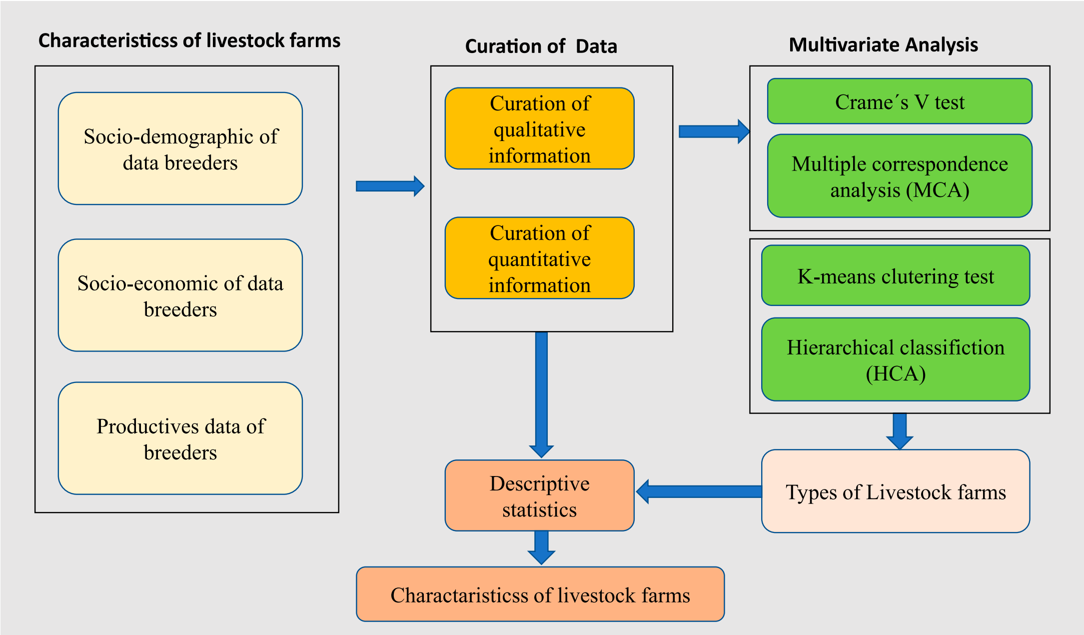


FIGURE 1
Flowchart for classifying farms practising mixed livestock systems.

## Multivariate analysis

Ten pertinent categorical variables were selected to classify mixed breeding according to sociodemographic, socioeconomic, dietary, reproductive management, and health indicators (Table 1). The variables were selected based on the variability of responses gathered and their relevance to livestock breeding. The procedure used to characterize the mixed livestock farms is illustrated in Figure 1. The assembled data were examined with a multivariate strategy that comprised multiple correspondence analysis (MCA), following an assessment of the contingency association and the presence of multicollinearity among the variables using Cramer's V coefficient. Dimensional conservation was defined using Greenacre's average inertia criterion (Nenadic and Greenacre, 2007) (Supplementary Table S1). Subsequently, the MCA coordinates were clustered using hierarchical cluster analysis (HCA). Euclidean distance was used as the similarity measure, and Ward's method was used as the aggregation criterion (Vila-Baños et al., 2014). The number of groups (clusters) was determined using the "elbow" method, which is based on the principle of intragroup inertia analysis. Finally, the clusters were consolidated using the K-means algorithm in hierarchical principal component classification (HCPC). Differences in the chosen variables among groups were evaluated using the chi-square test.

MCA is an unsupervised learning method used to reveal and visualize structures in large, multidimensional categorical datasets. In this framework, the distances between categories are interpreted as reflecting the strength of their relationships. When two categories appear close to one another in the spatial map, this indicates a direct association between them (Greenacre, 2017). By contrast, HCA is designed to group observations according to their intrinsic similarity. Elements belonging to the same cluster share greater resemblance with one another than with elements in other clusters (Kameshwaran and Malarvizhi, 2014; Shetty and Singh, 2021). This algorithm iteratively improves the clustering solution by reducing the standard deviation within clusters and increasing the standard deviation between clusters (Eshetae et al., 2024), thereby dividing the dataset into distinct, non-overlapping subgroups, where each data point is assigned to exactly one cluster (Likas et al., 2003).

# Results

## Sociodemographic characteristics

The findings showed that men were more involved in livestock production (59.43%), especially in the districts of Chuschi and Chipao. In Chuschi, most breeders were Quechua speakers (68.18%), while in the other districts both Quechua and Spanish are used. A larger share of illiterate breeders was found in Sacsamarca and Chipao; in Chuschi, 62.69% had completed primary education, whereas in Sancos, 40.63% had finished secondary education. In this study, stone houses were the predominant type of dwelling, and these typically relied on solar panels for energy. Springs represented the primary water source for breeders. Compared with the other districts, breeders in Chuschi enjoyed better access to basic services such as water, electricity networks, and adequate housing (Supplementary Table S1).

## Socioeconomic characteristics

In this study, it was the men who made the decisions regarding livestock-related activities. Specifically, in Sancos, sheep were raised under a partnership system, in which the partners were responsible

TABLE 2 Socioeconomic characteristics in mixed livestock farm at the four districts of the high Andean region of Ayacucho, Peru.

| Socioeconomic | Districts | | | | | | | | Total (N = 175) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Chushi (N = 67) | | Sancos (N = 32) | | Sacsamarca (N = 39) | | Chipao (N = 37) | | | |
| | N | % | N | % | N | % | N | % | N | %* |
| **Source of income** | | | | | | | | | | |
| Agriculture | - | - | - | - | 2 | 5.13 | - | - | 2 | 1.14 |
| Livestock | 67 | 100.00 | 28 | 87.50 | 32 | 82.05 | 37 | 100.00 | 164 | 93.71 |
| Trade | - | - | 2 | 6.25 | 4 | 10.26 | - | - | 6 | 3.43 |
| Temporary labor | - | - | 1 | 3.13 | - | - | - | - | 1 | 0.57 |
| Other | - | - | 1 | 3.13 | 1 | 2.56 | - | - | 2 | 1.14 |
| **Area extension** | | | | | | | | | | |
| <3 ha | 40 | 59.70 | 5 | 13.16 | 14 | 35.90 | 10 | 27.03 | 69 | 38.12 |
| 3–5 ha | 16 | 23.88 | 5 | 13.16 | 5 | 12.82 | 5 | 13.51 | 31 | 17.13 |
| 6–10 ha | 3 | 4.48 | 5 | 13.16 | 8 | 20.51 | 2 | 5.41 | 18 | 9.94 |
| >10 ha | 8 | 11.94 | 23 | 60.53 | 12 | 30.77 | 20 | 54.05 | 63 | 34.81 |
| **Type of irrigation** | | | | | | | | | | |
| Gravity | 19 | 28.36 | 4 | 12.50 | 8 | 21.05 | 7 | 18.92 | 38 | 21.84 |
| Sprinkling | 30 | 44.78 | 1 | 3.13 | 4 | 10.53 | 4 | 10.81 | 39 | 22.41 |
| Drip | 0 | - | 1 | 3.13 | 0 | - | 0 | - | 1 | 0.57 |
| Does not use irrigation | 18 | 26.87 | 26 | 81.25 | 26 | 68.42 | 26 | 70.27 | 96 | 55.17 |

*The percentage is presented by column, where the sum of each of the modalities adds up to 100%.

TABLE 3 Technical assistance and training services for breeders in mixed livestock farms in the high Andean region of Ayacucho, Peru.

| Entity | Respondent | | Theme |
|---|---|---|---|
| | N | % | |
| Regional agrarian directorate | 37 | 21.14 | Artificial insemination, feed management, heat detection, and health in cattle; food, health, and reproductive management in alpacas; and genealogical registration in alpacas |
| Instituto nacional de innovación agraria | 6 | 3.43 | Use of purebred animals, reproductive biotechnology, and heat synchronization in cows; phenotypic characterization of alpacas |
| AGRORURAL | 10 | 5.71 | Grazing system, pasture installation, supplementation, health, animal welfare in sheep and alpacas |
| NGOs | 9 | 5.14 | Pasture management in sheep |
| National agricultural health service | 3 | 1.71 | Animal health and welfare |
| No access to technical assistance and training | 110 | 62.87 | - |

AGRORURAL: Programa de Desarrollo Productivo Agrario Rural; NGOs, Non-Governmental Organizations. The topics of the training sessions that the ranchers received at least once from the institutions described in Table 4 are mentioned.

for managing and deciding about their respective farms. The breeders' socioeconomic characteristics are presented in Table 2. Compared with crop cultivation, livestock rearing was the primary economic activity of the breeders. Most breeders (71.84%) had been raising livestock for more than 21 years, and they identified the main social problem as lack of government support (64.29%), followed by migration (31.55%). Most breeders (38.12%) reported that they owned less than 3 ha of land, particularly in Chuschi, while

TABLE 4 **Livestock numbers by species that make up the mixed farms of the four districts at the high Andean region of Ayacucho, Peru.**

| Livestock population | Chushi | Sancos | Sacsamarca | Chipao | p-value |
|---|---|---|---|---|---|
| | ME ± ES | ME ± ES | ME ± ES | ME ± ES | |
| Cattle | 12.25 ± 3.82$^{b}$ | 38.27 ± 4.33$^{a}$ | 41.74 ± 5.57$^{a}$ | 23.25 ± 7.30$^{ab}$ | <0.0000*** |
| Cow in lactation | 4.11 ± 0.40$^{b}$ | 14.33 ± 2.16$^{a}$ | 8.20 ± 2.73$^{ab}$ | 6.88 ± 2.08$^{ab}$ | 0.0008*** |
| Dry cow | 2.36 ± 0.37$^{b}$ | 9.69 ± 1.93$^{a}$ | 5.40 ± 2.20$^{ab}$ | 5.50 ± 1.57$^{ab}$ | 0.0003*** |
| Pregnant heifer | 2.00 ± 0.46$^{b}$ | 6.08 ± 1.08$^{a}$ | 4.00 ± 0.58$^{ab}$ | 1.6 ± 0.24$^{b}$ | 0.0010*** |
| Heifer | 1.83 ± 0.32$^{b}$ | 9.15 ± 2.04$^{a}$ | 4.4 ± 0.81$^{b}$ | 3.00 ± 0.00$^{b}$ | 0.0001*** |
| Bull | 2.25 ± 0.75 | 1.40 ± 0.40 | - | - | 0.0987 |
| Young bull | 1.50 ± 0.26$^{b}$ | 4.29 ± 0.92$^{a}$ | 2.5 ± 0.87$^{ab}$ | 3.25 ± 0.95$^{ab}$ | 0.0048** |
| Calves | 3.63 ± 0.51$^{b}$ | 15.07 ± 2.23$^{a}$ | 10.17 ± 2.17$^{a}$ | 6.75 ± 2.13$^{b}$ | 0.0000*** |
| Sheep | 68.00 ± 11.04$^{c}$ | 411.50 ± 49.87$^{a}$ | 241.76 ± 40.98$^{b}$ | 30.59 ± 3.40$^{c}$ | <0.0000*** |
| Adult female | 59.08 ± 6.52$^{b}$ | 221.61 ± 29.55$^{a}$ | 126.19 ± 21.09$^{b}$ | 25.12 ± 4.36$^{b}$ | <0.0000*** |
| Ram | 4.62 ± 0.93 | 8.68 ± 1.84 | 5.92 ± 1.78 | 3.38 ± 0.73 | 0.0924 |
| Lamb | 12.9 ± 5.00$^{b}$ | 69.93 ± 12.10$^{a}$ | 42.25 ± 11.92$^{a}$ | 7.75 ± 1.92$^{b}$ | <0.0000*** |
| Young female | 21.58 ± 5.32$^{c}$ | 65.92 ± 8.94$^{a}$ | 36.8 ± 10.35$^{ab}$ | 11.14 ± 3.91$^{b}$ | 0.0003*** |
| Young male | 21.58 ± 5.88$^{c}$ | 71.59 ± 10.55$^{a}$ | 31.31 ± 7.11$^{ab}$ | 9.12 ± 3.34b$^{c}$ | 0.0000*** |
| Alpaca | 104.9 ± 13.27$^{a}$ | 131.83 ± 41.92$^{ab}$ | 103.76 ± 14.29$^{a}$ | 189.06 ± 17.27$^{b}$ | 0.0005*** |
| Adult female | 47.56 ± 5.44$^{b}$ | - | 48.90 ± 10.71$^{ab}$ | 77.96 ± 7.53$^{a}$ | 0.0013** |
| Adult male | 6.31 ± 1.20$^{a}$ | - | 1.90 ± 0.38$^{b}$ | 5.29 ± 0.76$^{a}$ | 0.0045** |
| Neonate alpaca | 40.82 ± 4.81$^{b}$ | - | 39.60 ± 6.29$^{b}$ | 80.04 ± 6.32$^{a}$ | <0.0000*** |
| Tuis | 14.59 ± 2.00$^{b}$ | - | 15.30 ± 2.96$^{b}$ | 33.61 ± 3.15$^{a}$ | 0.0000*** |
| Neutered | 7.45 ± 1.68$^{b}$ | - | 7.20 ± 2.11$^{b}$ | 13.41 ± 1.83$^{a}$ | 0.0324* |
| Llama | 33.67 ± 8.99$^{a}$ | 10.75 ± 6.45$^{ab}$ | 43.25 ± 21.27$^{a}$ | 22.56 ± 5.52$^{a}$ | 0.2386* |
| Goat | 4.67 ± 3.18 | 2 ± 00 | 1.5 ± 0.50 | - | 0.6265Ns |
| Hen | 5.38 ± 0.81 | 4.33 ± 1.23 | 6.17 ± 1.40 | 6.89 ± 2.20 | 0.7110 Ns |
| Guinea pigs | 28.52 ± 6.62 | 10 ± 00 | 7.5 ± 2.50 | 24.25 ± 9.90 | 0.5234 Ns |

a,b,c Different superscript letters within the same row indicate statistically significant differences between groups ($p < 0.05$). ME: medium; ES: standard error; N.s., not significant ($p > 0.05$); *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

34.81% owned more than 10 ha. In addition, 55.17% of the breeders reported that their farms had no access to water, and among those who did have access, water was obtained from irrigation ditches (40.24%), rivers (29.27%), and other sources such as reservoirs (23.17%).

Table 3 presents information on breeders' access to training and technical assistance provided by institutions (both private and public) dedicated to the sector. More than half of the breeders (62.87%) reported not receiving any technical assistance or training, while the remaining percentage had participated in at least one training event within the last 2 years. The regional government, through productive projects focused on cattle, sheep, and camelids, plays a leading role in technology transfer to breeders, whereas other sector institutions have a more limited involvement.

Cattle were raised primarily for dairy production (85.11%), especially cheese and related products; in Sacsamarca in particular, in addition to processed dairy products, whole milk was also marketed. Sheep were mainly kept for live sale (74.14%), although some producers additionally sold meat (8.62%). Alpacas were raised for both fiber and meat (66.15%), although a portion of breeders focused exclusively on fiber production (32.31%). Llamas, meanwhile, were raised predominantly for meat sales (92.29%).

## Productive characteristics

### Livestock population and facilities

The breeding system in the sectors was largely extensive. In 37% of cases, the animals were kept together in a single pen on the farm, mainly alpacas, llamas, or sheep. Most breeders did not have adequate infrastructure for their livestock, and even those who had it generally did not use it. The majority had grazing areas

TABLE 5 Feeding practices applied in mixed livestock farms at the four districts of the high Andean region of Ayacucho, Peru.

| Feeding | District | | | | | | | | Total (N = 175) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Chushi (N = 67) | | Sancos (N = 32) | | Sacsamarca (N = 39) | | Chipao (N = 37) | | | |
| | N | % | N | % | N | % | N | % | N | %* |
| **Grazing system** | | | | | | | | | | |
| Continuous | 35 | 52.24 | 14 | 43.75 | 21 | 53.85 | 31 | 83.78 | 101 | 57.71 |
| Rotational | 25 | 37.31 | 10 | 31.25 | 8 | 20.51 | 4 | 10.81 | 47 | 26.86 |
| Seasonal | 6 | 8.96 | 8 | 25.00 | 10 | 25.64 | 2 | 5.41 | 26 | 14.86 |
| Others | 1 | 1.49 | - | - | - | - | - | - | 1 | 0.57 |
| **Type of grass** | | | | | | | | | | |
| Natural | 24 | 35.82 | 23 | 71.88 | 22 | 56.41 | 27 | 72.97 | 96 | 54.86 |
| Cultivated | - | - | 4 | 12.50 | 8 | 20.51 | 2 | 5.41 | 14 | 8.00 |
| Natural + cultivated | 43 | 64.18 | 5 | 15.63 | 9 | 23.08 | 8 | 21.62 | 65 | 37.14 |
| **Supplement** | | | | | | | | | | |
| Roughage | 2 | 2.99 | 1 | 3.13 | - | - | 4 | 10.81 | 7 | 4.00 |
| Oat hay | 40 | 59.70 | 6 | 18.75 | 11 | 28.21 | 13 | 35.14 | 70 | 40.00 |
| Own balanced | 1 | 1.49 | - | - | 3 | 7.69 | - | - | 4 | 2.29 |
| Balanced trade | - | - | - | - | 3 | 7.69 | 3 | 8.11 | 6 | 3.43 |
| Minerals and vitamins | 3 | 4.48 | 9 | 28.13 | 12 | 30.77 | 14 | 37.84 | 38 | 21.71 |
| No supplement | 15 | 22.39 | 1 | 3.13 | - | - | 1 | 2.70 | 17 | 9.71 |
| Other | 6 | 8.96 | 15 | 46.88 | 10 | 25.64 | 2 | 5.41 | 33 | 18.86 |

*The percentage is presented by column, where the sum of each of the modalities adds up to 100%.

for cattle and corrals for alpacas and sheep, but there was a shortage of barns, water troughs, feeders, and handling chutes. Breeders in Sancos, Chipao, and Sacsamarca were using communal natural pasture lands ranging from 10 to 500 ha, which were not clearly demarcated.

Table 4 presents the average number of animals per species and category in the farms. Sheep represented the largest number of heads (25,669), followed by alpacas (14,030), cattle (3,233), and llamas (723), whereas goats, birds, and guinea pigs were present only in very small numbers. The mean populations of cattle, sheep, alpacas, and llamas differed significantly among districts ($p < 0.05$). The highest average numbers of cattle and sheep were found in Sacsamarca and Sancos, while Chipao had the largest average alpaca population.

## Feeding

Table 5 presents information on the feeding systems used by breeders. In all livestock farms, the animals were managed using pasture-based feeding systems, with continuous grazing being the most common (57.71%), followed by rotational grazing (26.86%) and seasonal grazing (14.86%). Continuous grazing was mainly applied to sheep and camelids, whereas rotational grazing was more frequently used for cattle. Some breeders transferred their livestock between different areas as a seasonal feeding strategy. Natural pasture was the primary feed resource for cattle, although some farms used a combination of natural and cultivated pastures. Cattle were the species that most frequently grazed on cultivated pastures; only a few breeders provided these pastures to alpacas.

Communal property was the main food source for the livestock of most breeders. 90.23% of breeders supplemented their livestock, mainly with hay, vitamins and minerals, mainly in the dry season. Breeders also reported that rivers, ditches, and water holes are the main sources of water for their livestock. Camelids were the species that consumed the most water from natural springs, while cattle and sheep did so from rivers and ditches.

The pastures commonly consumed by livestock species are shown in Table 6. The cultivated pastures were mainly offered to cattle, and only in the dry season they were offered to sheep and alpaca. The native pastures of the area, among them: them bofedales, canllares, juncaceas, grasslands, and tolares, were mainly used by sheep and camelids.

## Productive and reproductive management

In the study areas, over half of the breeders (71.05%) had incorporated exotic cattle breeds into their farm over the past 5 years, predominantly the Brown Swiss breed (92.59%). The

TABLE 6 List of plant species in cultivated and natural pastures utilized and their usage by the respective livestock in the study sectors.

| Scientific name | Common name | N (%) | Species they consume |
|---|---|---|---|
| *Medicago sativa* | Alfalfa | (10/175) 5.71 | Cattle |
| *Trifolium pratense* | Red clover | (6/175) 3.43 | Cattle |
| *Trifolium repens* | White clover | (8/175) 4.57 | Cattle, sheep |
| *Lolium multiflorum* | Rye grass italiano | (9/175) 5.14 | Cattle and sheep |
| *Lolium perenne* | Rye grass, English | (4/175) 2.29 | Cattle, sheep, and alpaca |
| *Dactylis glomerata* | Dactilys | (9/175) 5.14 | Cattle, sheep, and alpaca |
| *Avena sativa* | Oat | (38/175) 21.71 | Cattle, sheep, alpaca, and llama |
| *Stipa ichu* | Ichu | (6/175) 3.43 | Cattle, sheep, alpaca, and llama |
| *Festuca dolichophylla* | Chillihua | (7/175) 4.00 | Cattle, alpacas, and llamas |
| *Oroya peruviana* | Chocco | (12/175) 6.86 | Sheep and alpacas |
| *Bromus lanatus* | Soqlla | (3/175) 1.71 | Cattle, sheep, and alpacas |
| *Paspalum pygmaeum* | Sara sara | (1/175) 0.57 | Sheep and alpacas |
| *Calamagrostis vicunarum* | Crespillo | (3/175) 1.71 | Alpacas and llamas |
| | Bofedal (a family of natural grasses) | (19/175) 10.86 | Alpacas |
| | Natural grass (not specified) | (41/175) 23.44 | Cattle, sheep, alpaca, and llama |

TABLE 7 Genetic material management in mixed livestock farms at the four districts of the high Andean region of Ayacucho, Peru.

| Genetic management and reproduction | District | | | | | | | | Total (N = 175) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Chushi (N = 67) | | Sancos (N = 37) | | Sacsamarca (N = 39) | | Chipao (N = 37) | | | |
| | N | % | N | % | N | % | N | % | N | %* |
| **Purchase of breeding stock** | | | | | | | | | | |
| None | 29 | 43.28 | 7 | 21.21 | 10 | 25.64 | 18 | 48.65 | 64 | 36.36 |
| From neighbor | 11 | 16.42 | 6 | 18.18 | 10 | 25.64 | 8 | 21.62 | 35 | 19.89 |
| From the region | 16 | 23.88 | 10 | 30.30 | 8 | 20.51 | 9 | 24.32 | 43 | 24.43 |
| National | 1 | 1.49 | 8 | 24.24 | 9 | 23.08 | 1 | 2.70 | 19 | 10.80 |
| Exchange | 4 | 5.97 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 4 | 2.27 |
| Insemination | 6 | 8.96 | 2 | 6.06 | 2 | 5.13 | 1 | 2.70 | 11 | 6.25 |

*The percentage is presented by column, where the sum of each of the of the modalities adds up to 100%.

districts of Chuschi and Sancos showed the greatest interest in introducing exotic sheep breeds, where Chuschi mainly selected the Merino breed (52.94%), while Sancos favored the Corriedale breed (50.00%). In addition, the Hampshire Down breed had been introduced across all four boroughs.

Natural mating was the predominant breeding method; however, a portion of breeders (30.77%), specifically cattle, employed artificial insemination (AI). The livestock projects carried out by the regional government are those that provide the genetic material for AI in cattle and assigned technical staff for its application. The reproductive period in cattle was recorded throughout the year, whereas sheep breeding occurred during two specific periods: December–February and May–July. In camelids, breeding was restricted to a single annual season, from December to March. For natural mating within the farm, breeding males were obtained mainly from the same farm, while other breeders acquired them from neighboring breeders or from breeders within and/or outside the region (Table 7).

## Milking management

Hand-milking was practiced by all breeders in the study areas. Breeders in Sancos and Sacsamarca generally only milked during the pasture season (December–May), which meant their milk

TABLE 8 **Fiber shearing management in alpacas from mixed livestock farms at the four districts of in the high Andean region of Ayacucho, Peru.**

| Shearing management | Districts | | | | | | Total (N = 65) | |
|---|---|---|---|---|---|---|---|---|
| | Chuschi (N = 30) | | Sacsamarca (N = 10) | | Chipao (N = 25) | | | |
| | N | % | N | % | N | % | N | %* |
| **Fiber/Animal weight** | | | | | | | | |
| <5 lbs | 23 | 76.67 | 7 | 70.00 | 17 | 68.00 | 47 | 72.31 |
| 5–7 lbs | 7 | 23.33 | 2 | 20.00 | 7 | 28.00 | 16 | 24.62 |
| >8 lbs | - | - | 1 | 10.00 | 1 | 4.00 | 2 | 3.08 |
| **Time between shears** | | | | | | | | |
| Annual | 22 | 73.33 | 5 | 50.00 | 13 | 52.00 | 40 | 61.54 |
| Every 2 years | 7 | 23.33 | 5 | 50.00 | 11 | 44.00 | 23 | 35.38 |
| Every 3 years | 1 | 3.33 | - | - | 1 | 4.00 | 2 | 3.08 |
| **Shearing season** | | | | | | | | |
| January-March | - | - | - | - | 12 | 48.00 | 12 | 18.46 |
| April-June | 21 | 70.00 | 9 | 90.00 | - | - | 30 | 46.15 |
| July-September | 4 | 13.33 | 1 | 10.00 | 1 | 4.00 | 6 | 9.23 |
| October-December | 5 | 16.67 | - | - | 12 | 48.00 | 17 | 26.15 |

*The percentage is presented by column, where the sum of each of the modalities adds up to 100%.

production campaign lasted 5 months. In contrast, in Chipao and Chuschi, milking was carried out year-round, with production campaigns extending from 6 to 8 months. Peak milk yields occurred in the rainy season (January–March), when pasture availability was greatest. A total of 76.32% of breeders reported that they did not conduct mastitis tests, while 13.16% did so only when deemed necessary. Most breeders (82.05%) knew the withdrawal period required before milk could be consumed after antibiotic treatment, although a proportion of them (12.82%) reported not using antibiotics at all.

### Shearing management

Alpaca shearing was performed in the resting pens. Table 8 presents the data on shearing management in alpacas. Shearing was performed in the resting pens, where most animals (72.31%) yielded less than 5 pounds of fleece per animal, followed by 24.62% that produced between 5 and 7 pounds per animal. In Chuschi and Sacsamarca, alpaca shearing took place mainly from April to May, whereas in Chipao it was carried out between December and March. In Sancos, no shearing activities were recorded for camelids.

### Healthcare

Pneumonia was the most common disease in cattle (41.67%), followed by digestive disorders (colibacillosis, coccidiosis, and clostridiosis) (20.83%), particularly in calves; external parasitic infestations (10.42%) and malnutrition (12.50%) were also frequent. Sheep were most often affected by pneumonia (20.55%) and by dystomatosis (19.18%). By locality, Chuschi showed the highest frequency of dystomatosis (52.00%), Sancos had more cases of photosensitization (31.58%), and Sacsamarca reported the highest rate of pneumonia (31.82%). In alpaca crias, colibacillosis (30.11%) and pneumonia (15.05%) were the predominant problems. Chuschi presented more cases of colibacillosis, while Chipao had a higher occurrence of scabies and alpaca fever.

Table 9 presents information on sanitary management in mixed livestock farms. No veterinary care was provided to the livestock; instead, the breeders themselves were responsible for maintaining animal health. Illnesses such as pneumonia, malnutrition, and alpaca fever appeared mainly from July to September, a period characterized by lower temperatures and limited water availability, whereas digestive disorders occurred predominantly from January to March, during the rainy season.

Most breeders acquired veterinary products for their veterinary kit after professional advice, while the others depended only on the experience gained within their own farm. Only 38.46% of breeders vaccinated their cattle against symptomatic anthrax; sheep and camelids were generally not vaccinated, although some animals did receive vaccines against foot-and-mouth disease and enterotoxemia. Parasite control was applied uniformly across the farms, timed to the beginning and end of the rainy season.

## Marketing and stakeholders

Table 10 presents product sales based on what each livestock species provides. Cattle were raised mainly for dairy production. In Chuschi, breeders concentrated on making quesillos; in Sancos and

TABLE 9 Sanitary management practices in mixed livestock farms at the four districts of in the high Andean region of Ayacucho, Peru.

| Health management | District | | | | | | | | Total (N = 175) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Chuschi (N = 67) | | Sancos (N = 37) | | Sacsamarca (N = 39) | | Chipao (N = 37) | | | |
| | N | % | N | % | N | % | N | % | N | %* |
| **Veterinary care** | | | | | | | | | | |
| Status professional | 2 | 2.99 | 0 | 0.00 | 2 | 5.13 | 0 | 0.00 | 4 | 2.29 |
| Private professional | 6 | 8.96 | 5 | 15.63 | 6 | 15.38 | 1 | 2.70 | 18 | 10.29 |
| State technician | 2 | 2.99 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 2 | 1.14 |
| Private technician | 1 | 1.49 | 2 | 6.25 | 3 | 7.69 | 3 | 8.11 | 9 | 5.14 |
| Promoter | 2 | 2.99 | 0 | 0.00 | 1 | 2.56 | 0 | 0.00 | 3 | 1.71 |
| The owner | 51 | 76.12 | 25 | 78.13 | 25 | 64.10 | 33 | 89.19 | 134 | 76.57 |
| Does not perform | 3 | 4.48 | 0 | 0.00 | 2 | 5.13 | 0 | 0.00 | 5 | 2.86 |
| **Veterinary kit acquisition criteria** | | | | | | | | | | |
| Professional advisor | 34 | 50.75 | 19 | 59.38 | 14 | 36.84 | 8 | 21.62 | 75 | 43.10 |
| Breeder's own experience | 22 | 32.84 | 11 | 34.38 | 19 | 50.00 | 20 | 54.05 | 72 | 41.38 |
| Neighbor's advice | 4 | 5.97 | 1 | 3.13 | 0 | 0.00 | 2 | 5.41 | 7 | 4.02 |
| It does not count | 7 | 10.45 | 1 | 3.13 | 5 | 13.16 | 7 | 18.92 | 20 | 11.49 |
| **Parasite control** | | | | | | | | | | |
| 3 times a year | 15 | 30.00 | 10 | 52.63 | 18 | 72.00 | 17 | 48.57 | 60 | 46.51 |
| 2 times a year | 21 | 42.00 | 8 | 42.11 | 7 | 28.00 | 14 | 40.00 | 50 | 38.76 |
| 1 time a year | 9 | 18.00 | 1 | 5.26 | 0 | - | 1 | 2.86 | 11 | 8.53 |
| When needed | 5 | 10.00 | 0 | - | 0 | - | 3 | 8.57 | 8 | 6.20 |

*The percentage is presented by column, where the sum of each of the modalities adds up to 100%.

Sacsamarca, on producing both cheese and quesillos; and in Chipao, exclusively on cheese. Sheep, on the other hand, were raised primarily for live animal sales, with Sancos and Sacsamarca enjoying the greatest advantage in this regard. Sale prices varied according to animal size, breed, and locality. Finally, alpaca fiber was also commercialized, with Chipao standing out as the main producer, followed by Chuschi and Sacsamarca.

Most breeders relied on intermediaries to market their products (cheese, lamb, and fiber). The largest volumes of cheese were sold between December and May. Lamb and culled ewes were mainly marketed from April to June; however, in Sancos, sales took place in two periods: April–June and October–December, with some breeders selling animals due to financial pressures. Regarding fiber, sales in Chuschi and Sacsamarca occurred mostly between April and June, while in Chipao they were concentrated from December to March.

## Mixed livestock farm typology

The MCA was performed using 10 categorical variables comprising 46 categories, and the first three dimensions were retained for interpretation, as they account for 20.60% of the total variance; according to the scree plot, these dimensions exceeded the average inertia criterion and contributed most clearly to explaining differences among breeders (Supplementary Table S1). The coordinates, the quality of the presentation (Cos2), and the contribution of the variables to the three retained dimensions are shown in the supplementary table (Supplementary Table S2). While the remaining dimensions were disregarded due to their minimal contribution to the overall variation.

Figure 2 presents the distribution of farms along dimensions one and two. In the first dimension (eigenvalue 0.329), positive coefficients are breeders with houses built of adobe equipped with electricity they are characterized by having small livestock farms with natural and cultivated pasture areas covering less than 5 ha; they use sprinkler irrigation for the cultivated areas; for their livestock, they primarily use a rotational grazing system. Breeders use AI to improve their livestock, particularly cattle, and rely primarily on government professionals for health management. On the other hand, among those with negative coefficients are breeders whose homes are built of stone and lack basic services; they depend on natural pastures but do not have access to water and simply wait for the rainy season to arrive. The detailed coordinates, contributions and $cos^2$ values for each category are set out in Supplementary Table S1.

TABLE 10 **Average sales management of cheese, cheese, lamb and fiber in mixed livestock farms in the high Andean region of Ayacucho, Peru.**

| Product sales | Measurement | Chushi | Sancos | Sacsamarca | Chipao |
|---|---|---|---|---|---|
| **Cattle** | | | | | |
| Quesillo/week | Kg | 101.00 | 33.00 | 27.25 | - |
| Value | (S/. 10 Peruvian) | 1.30 | 3.00 | 3.00 | - |
| Cheese/week | Kg | - | 29.50 | 26.10 | 38.75 |
| Value | (S/. 12 Peruvian) | | 11.80 | 10.80 | 7.80 |
| **Sheep** | | | | | |
| Lamb/year | Kg of live weight | 8.33 | 72.11 | 23.36 | 6.67 |
| Value | (S/. 7.5 Peruvian) | 123.33 | 139.44 | 109.64 | 86.67 |
| Adult females/years | Kg of live weight | 13.95 | 35.32 | 29.80 | 4.50 |
| Value | (S/. 5.7 Peruvian) | 129.52 | 173.18 | 141.33 | 146.67 |
| **Alpaca** | | | | | |
| Fiber/year | Pounds | 66.31 | - | 93.89 | 139.38 |
| Value | (S/. 18 Peruvian) | 16.03 | - | 14.11 | 17.63 |

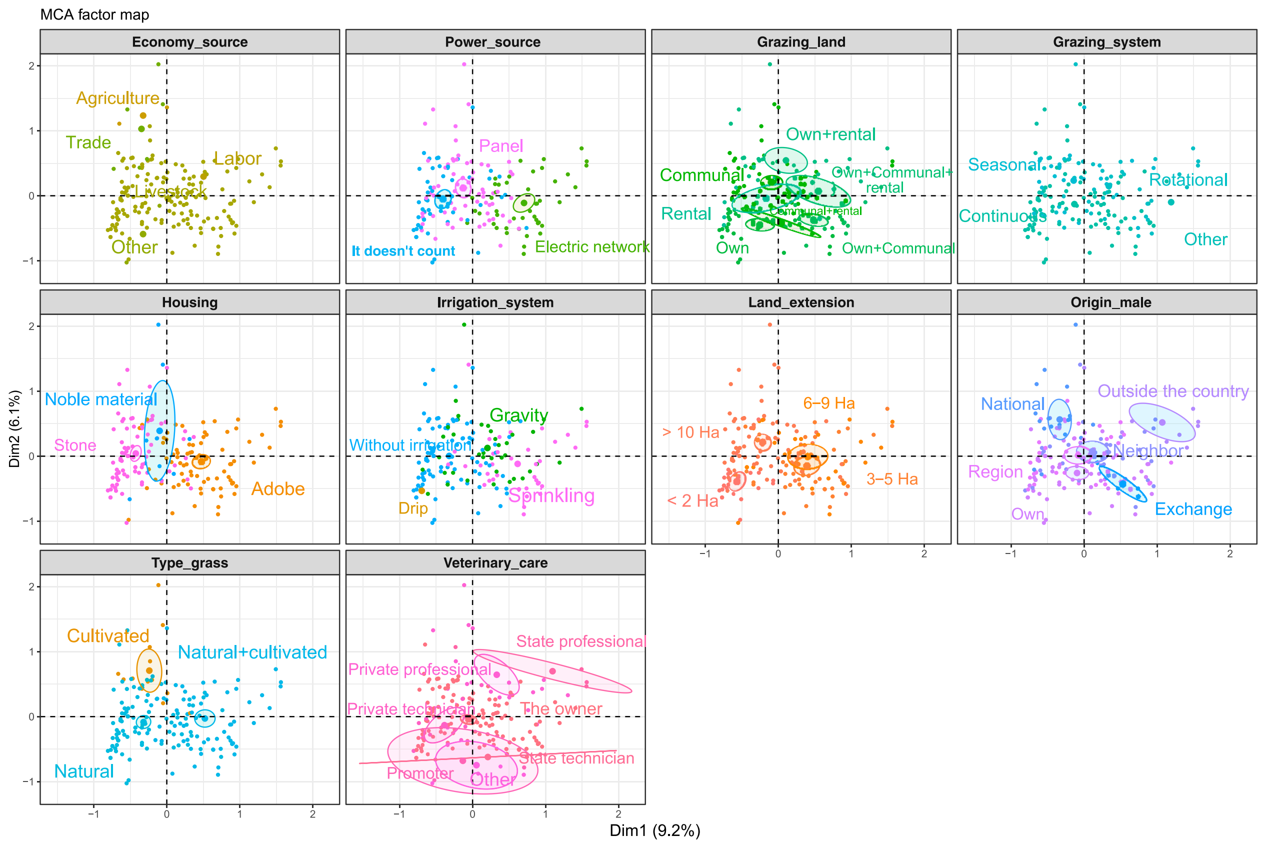


FIGURE 2
Scatter plot of the categories between the first and second dimensions that contribute to each study variable.

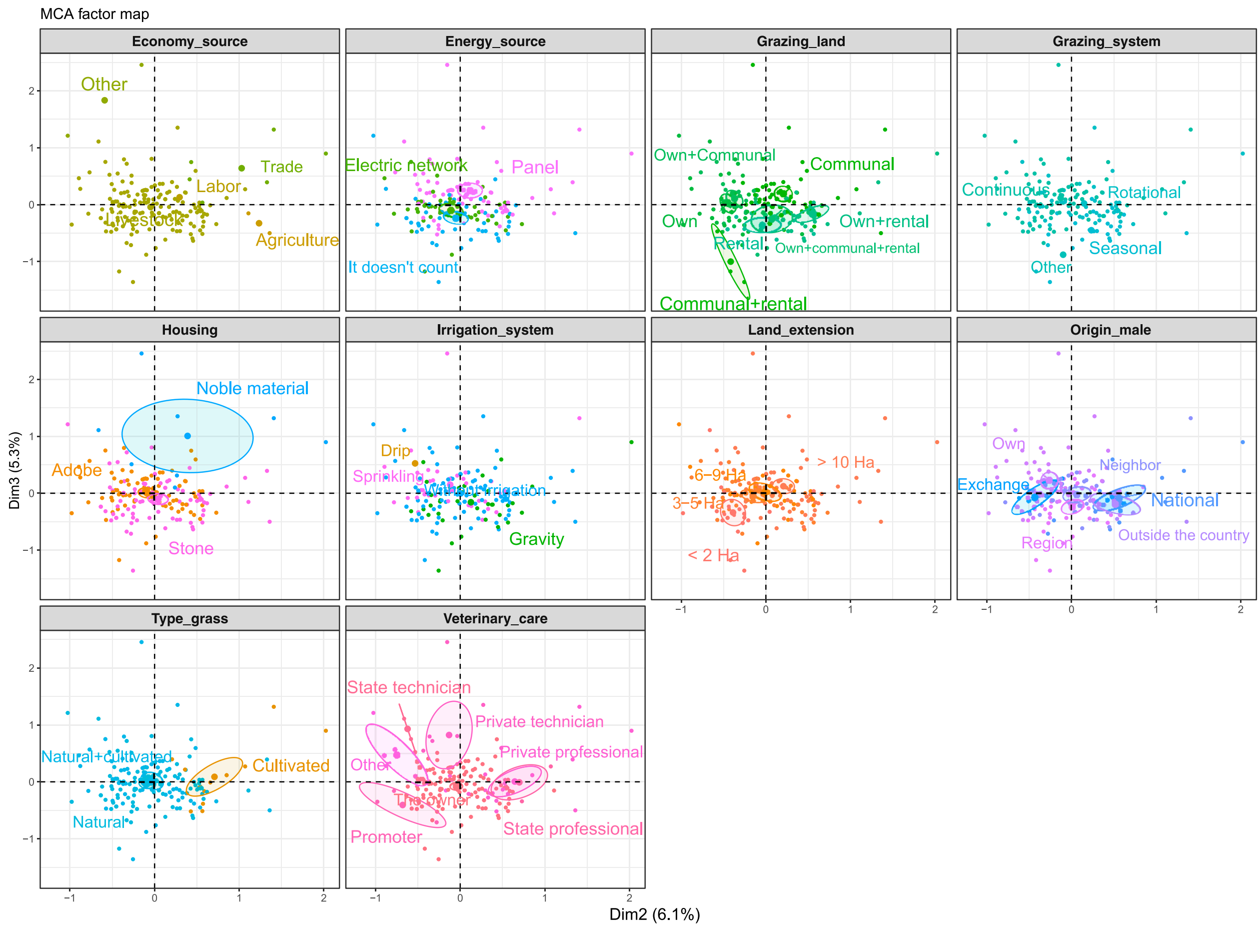


FIGURE 3
Scatter plot that the categories between the second and third dimensions that contribute to each study variable.

In contrast, the second dimension (eigenvalue 0.221), which has a positive coefficient, is characterized by breeders for whom, in addition to livestock, trade and agriculture were their main sources of income; they own large tracts of land with some cultivated pastures and, occasionally rent additional land when needed for their livestock; they source their breeding animals from other regions of the country, and sometimes their offspring are used for breeding; and they hired private professionals to handle sanitary management. For its part, the negative coefficient corresponds to breeders who owned small plots of land that they owned outright and who did not rely on professionals or technicians for disease control but rather on other people who had some knowledge of the subject. The detailed coordinates, contributions and $\cos^2$ values for each category are set out in Supplementary Table S1.

Figure 3 shows the distribution of farms along the second and third dimensions. When comparing the first and second dimensions, the positive coefficient of the third dimension (eigenvalue 0.192) includes breeders whose homes were built with high-quality materials, and most of whom have electricity from solar panels; in addition to livestock, they have other sources of income, such as other temporary jobs and trade; in terms of reproductive management, they do not bring in males from other areas but use their own; and they turned to private technicians and professionals for veterinary services. In the negative coefficient, this group is characterized by being composed of breeders with small plots of land; they graze their livestock seasonally on communal and leased lands. The detailed coordinates, contributions and $\cos^2$ values for each category are set out in Supplementary Table S1.

The hierarchical classification analysis made it possible to distinguish three groups of mixed livestock systems (Table 11; Figure 4; Supplementary Figures S1, S2). These three groups were classified based on ten selected variables, which were considered to exert the greatest influence on the heterogeneity of the production systems.

The first group is called "mixed livestock farm with small and large non-irrigated landholdings" (Figure 4, n = 34.29%). These breeders generally reside in stone houses (61%) lacking electricity (62%) and potable water. This group is characterized by having their land covered exclusively by natural rangelands (58%), with no irrigation water available (52%). The breeders in this group grazed their animals on a combination of their own plots (68%) and communal areas (31%), without any structured grazing management (47%). Reproduction relied on males from their own farm (48%) or purchased from other regions (40%), and the smallholders themselves handled (67%) any health issues affecting their animals.

TABLE 11 Distribution of respondent categories for the three groups identified by the HCA.

| Variable | Group 1 | Group 2 | Group 3 | Total | p-value |
|---|---|---|---|---|---|
| Housing material | | | | | *** |
| Noble material | 1 | 6 | 1 | 8 | |
| Adobe | 6 | 9 | 65 | 80 | |
| Stone | 53 | 27 | 7 | 87 | |
| Power source | | | | | *** |
| Electrical network | 1 | 1 | 44 | 46 | |
| Panel | 23 | 25 | 23 | 71 | |
| It does not count | 36 | 16 | 6 | 58 | |
| Source of income | | | | | *** |
| Agriculture | 0 | 2 | 0 | 2 | |
| Livestock | 59 | 33 | 72 | 164 | |
| Trade | 0 | 6 | 0 | 6 | |
| Temporary labor | 0 | 0 | 1 | 1 | |
| Other | 1 | 1 | 0 | 2 | |
| Area of the property | | | | | *** |
| <2 ha | 22 | 2 | 0 | 24 | |
| 3–5 ha | 5 | 4 | 37 | 46 | |
| 6–10 ha | 4 | 6 | 18 | 28 | |
| >10 Ha | 29 | 31 | 18 | 78 | |
| Irrigation system | | | | | *** |
| Gravity | 7 | 11 | 18 | 36 | |
| Sprinkling | 2 | 2 | 35 | 39 | |
| Dripping | 1 | 0 | 0 | 1 | |
| No irrigation | 50 | 29 | 18 | 97 | |
| Grazing system | | | | | *** |
| Continuous | 47 | 16 | 38 | 101 | |
| Rotational | 5 | 14 | 28 | 47 | |
| Seasonal | 8 | 12 | 6 | 26 | |
| Other | 0 | 0 | 1 | 1 | |
| Type of grass they consume | | | | | *** |
| Natural | 56 | 18 | 22 | 96 | |
| Cultivated | 4 | 13 | 1 | 18 | |
| Natural + cultivated | 0 | 11 | 50 | 61 | |
| Cattle graze | | | | | *** |
| Own | 28 | 1 | 12 | 41 | |
| Communal | 19 | 21 | 22 | 62 | |
| Rental | 7 | 2 | 4 | 13 | |
| Own + communal | 2 | 0 | 18 | 20 | |

(*Continued*)

TABLE 11 Continued

| Variable | Group 1 | Group 2 | Group 3 | Total | p-value |
|---|---|---|---|---|---|
| Own + communal + rental | 1 | 3 | 6 | 10 | |
| Own + rental | 1 | 15 | 10 | 26 | |
| Communal + rental | 2 | 0 | 1 | 3 | |
| Purchase of breeding stock | | | | | *** |
| Own | 31 | 9 | 24 | 64 | |
| Neighbor | 10 | 6 | 20 | 36 | |
| Region | 17 | 10 | 16 | 43 | |
| National | 2 | 16 | 1 | 19 | |
| Exchange | 0 | 0 | 4 | 4 | |
| Outside the country | 0 | 1 | 8 | 9 | |
| Veterinary care | | | | | ** |
| State professional | 0 | 1 | 3 | 4 | |
| Private professional | 0 | 9 | 9 | 18 | |
| State technician | 1 | 0 | 1 | 2 | |
| Private technician | 6 | 3 | 0 | 9 | |
| Promoter | 2 | 0 | 1 | 3 | |
| The owner | 48 | 29 | 57 | 134 | |
| Does not perform | 3 | 0 | 2 | 5 | |

**p < 0.01, ***p < 0.001.

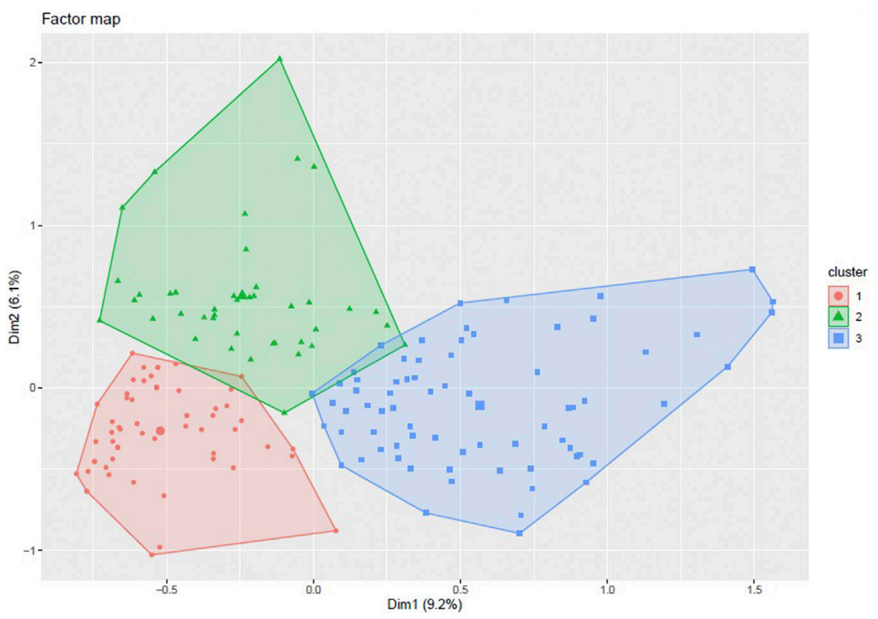


FIGURE 4
Hierarchical classification of mixed livestock farms run by small-scale breeders in the high Andean region of Ayacucho, Peru.

The second group is called "mixed livestock farm with extensive land areas" (Figure 4; n = 24.00%). This group comprised breeders who lived in stone-built houses (31%) and had access to electricity via panels (35%). This group is characterized by owning more than 10 ha of land (40%) with a mixture of natural (19%) and cultivated pastures (72%), part of which was supplied by gravity-fed irrigation (31%). Their livestock were managed under a rotational (30%) and seasonal (46%) grazing system, and they sourced breeding males from other regions (84%) of the country.

The third group is called "mixed livestock farm with medium-sized landholdings" (Figure 4; n = 41.71%). This group included breeders living in adobe houses (81%), with access to electricity (96%) and drinking water. This is characterized by managing between 3 and 10 ha (74%), consisting of natural and cultivated (82%) pastures, with the cultivated areas primarily irrigated by gravity (50%) and sprinkler (90%) systems. The breeders of this group grazed their flock in rotational (60%) and continuous (38%) grazing systems. For mating they used males from their own flocks (38%), from neighbors (56%), from another farm in the region (37%), and from abroad (89%). In this group, producers were more likely to seek professional support (75%) for health management.

## Discussion

This study presents the demographic and socioeconomic profile of breeders, as well as the livestock practices, management strategies, and constraints faced in mixed livestock farms. The findings are intended to inform policy-making in the livestock sector. No previous reports on the characterization of mixed livestock farms were found for the Ayacucho region.

### Socioeconomic and sociodemographic characterization

Agricultural and livestock production is marked by a diversity of systems, in which the socioeconomic, productive, and environmental challenges of the sector demand tailored public policies (Ayala et al., 2024). In this study, men were the main participants, similar to findings in countries such as Congo and Ethiopia (Mugumaarhahama et al., 2021; Eshetae et al., 2024). In contrast, in Tacna, women play a greater role in livestock activities (Salamanca et al., 2018). Just like in this study, livestock keepers, particularly those in highland areas, speak both their native languages (Quechua and Aymara) and Spanish (Salamanca et al., 2018). Currently, in the high Andean zones, livestock production is rapidly expanding while agricultural activity is declining, which promotes the participation of both women and men.

Most of the breeders in this study were over 50 years of age. Similar patterns have been observed in the regions of Pasco, Junín, and Huancavelica of Peru (Gamarra et al., 2019; Casas, 2023; Hinojosa et al., 2019). In contrast, in other countries such as Ethiopia, breeders were reported to be, at most, 50 years old (Eshetae et al., 2024). The proportion of breeders who completed primary and secondary education is comparable to that of goat breeders in Ayacucho (Palomino-Guerrera et al., 2024), but lower than that reported for breeders in the regions of Ica, Lima, Junín, Ancash, and Pasco of Peru (Sessarego et al., 2025; Paredes Chocce et al., 2024; Casas, 2023; Poma et al., 2021; Gamarra et al., 2019). The higher educational level in these other regions would be related to easier access to educational institutions and established agrarian policies.

In this study, most breeders lived in houses built from stone and adobe, without electricity or running water. These findings agree with those reported for breeders in Huancavelica (Hinojosa et al., 2019) but differ from the situation in northern Lima and Junín of Peru, where the breeders had houses built with durable material and equipped with electricity and potable water (Paredes Chocce et al., 2024; Casas, 2023). These differences in building materials help explain the degree of access to livestock farms because the breeders in this region raise their livestock at considerable distances from urban centers of neighboring breeders. This situation compels them to use locally available materials for housing construction, resulting in dwellings lacking basic services and access roads.

Livestock farming was identified as the principal income source for these families, which aligns with reports from other regions such as Ancash and Lima of Peru (Poma et al., 2021; Paredes Chocce et al., 2024), as well as from other countries like Ethiopia (Eshetae et al., 2024). However, other regions of Peru indicate that agriculture (Casas, 2023; Gamarra et al., 2019; Sessarego et al., 2025) and various temporary or informal jobs (Salamanca et al., 2018; Mugumaarhahama et al., 2021) constituted their main livelihood. This divergence can be explained by local geographic conditions and market access, as in some regions of Peru, due to the Andes Mountains, in some areas there is insufficient land suitable for livestock rearing (Torres, 2001), and it restricts access to markets for the sale of animal products (milk, cheese, and meat).

As in this study, Mallma et al. (2021) indicate that alpacas were raised to obtain both fiber and meat. In other regions of Peru, such as Pasco, cattle were reared for live sale (Gamarra et al., 2019), while in Junín they were raised mainly for milk production (Casas, 2023). In Ancash, sheep were kept as a form of financial reserve or savings (Poma et al., 2021). The production of milk, meat, fiber, and dairy products is driven by market demand. Therefore, it is crucial to understand the prerequisites, such as consumption habits and the cultural, social, and family traditions of rural populations, and to determine which livestock activity should be pursued to obtain meat, milk, or fiber (Missohou et al., 2004; Rewe et al., 2006).

### Productive characterization

The type of system used in livestock farming is defined by multiple factors, including how feed, labor, and equipment are managed. The presence of diverse and heterogeneous systems complicates decision-making in the sector (Morales-Jerrett et al., 2022). Nevertheless, in many regions of the world, such diversity is used as a strategy to better exploit natural resources (Sow et al., 2021).

#### Livestock population and facility management

In this study, the breeders grazed their cattle on cultivated pastures, whereas sheep and camelids were kept on open, unfenced pastures. Comparable findings have been reported in alpacas (Hinojosa et al., 2019). As in the present work, other regions also used resting pens made of wood, mesh, or stone (Mallma et al., 2021; Hinojosa et al., 2018; Paredes Chocce et al., 2024). In other countries, livestock were provided with facilities such as sheds, corrals, and terraces for their animals (Assefa et al., 2024).

Agricultural policies and limited accessibility may be contributing factors to the absence of adequate livestock infrastructure, because in this region, sheep and camelid farming are mainly carried out in remote and hard-to-reach places, and local authorities do not consider strengthening these livestock activities in their development plans.

The average size of cattle and sheep in this study exceeded that of cows and sheep in other regions such as Junín, Tacna, and Ancash (Casas, 2023; Salamanca et al., 2018; Puma et al., 2021); a similar pattern is observed in other countries, such as Ethiopia (Assefa et al., 2015; Assefa et al., 2024). In contrast, the mean number of alpacas was lower than that reported in the Huancavelica region of Peru (Hinojosa et al., 2019). The size of the cattle farm is linked to both the land area owned and the dominant productive activity in the region. In this study, breeders managed between 5 and 500 ha of land for their livestock, which consisted mainly of sheep and camelids.

## Feed management

The grazing-based feeding system observed in this study is consistent with findings reported in other regions of the world (Duguma and Janssens, 2021; Assefa et al., 2024). The use of natural pastures for sheep and cultivated pastures for cattle was a common practice, similarly documented by Palomino-Guerrera et al. (2024), Gamarra et al. (2019), and Casas (2023). In contrast, these results differ from those of Puma et al. (2021), Salamanca et al. (2018), and Paredes Chocce et al. (2024), who indicated that livestock such as goats and sheep were fed with balanced rations and crop residue stubble, in addition to native pastures. Overall, the way feed resources are managed is largely shaped by the agro-ecological conditions under which livestock production takes place (Nguluma et al., 2022). For example, in the north of Peru, in the dry forest, goat livestock feed mainly on haurango (Rodriguez-Vargar et al., 2025). In contrast, in the coastal valley, there is a greater dominance of agro-exporters, and their crop residues are utilized by cattle, sheep, and goats (Paredes Chocce et al., 2024). Meanwhile, in the inter-Andean and high Andean valleys, animals take advantage of crop residues (corn, fava beans, wheat, and potatoes) (Palomino-Guerrera et al., 2024).

Goats, sheep, and camelids are generally grazed in communal rangelands (Puma et al., 2021; Herz Sáenz, 2019; Hinojosa et al., 2018), whereas cattle are typically managed on their own lands (Gamarra et al., 2019; Casas, 2023). It is important to highlight that the farm had a large number of sheep and camelids, therefore requiring extensive forage areas, which they access only in communal zones, unlike cattle. Grazing practices differ considerably among breeders, where cattle are predominantly managed under rotational grazing, while sheep and camelids are mainly subjected to seasonal or continuous grazing systems. This management is confirmed by breeders in other regions of Peru (Mallma et al., 2021; Hinojosa et al., 2019; Casas, 2023).

Kashongwe et al. (2017) and Assefa et al. (2024) indicate that seasonal fluctuations are the main factor influencing pasture availability, which decreases during dry spells and consequently reduces livestock productivity. In the lands used by the surveyed holding, signs of overgrazing were evident. This practice reduces the soil's capacity for water infiltration and retention and damages its structure (Heitschmidt and Stuth, 1992). Thus, the adoption of a holistic and sustainable land management strategy is advised—one that accommodates multiple uses such as livestock production, reforestation, and crop cultivation (Zarria and Flores, 2015).

## Reproductive and genetic management

The breeders in this study reported that genetic enhancement is the main priority on their farms. In this regard, breeders introduced exotic genetic material into both cattle and sheep. Similar findings have been reported among breeders in Pasco, Junín, and Tacna regions (Salamanca et al., 2018; Gamarra et al., 2019; Casas, 2023). Regional and local government production projects are the main driving forces behind the use of imported genetic material via AI, particularly in cattle, while in sheep and camelids, natural mating was exclusively used. In these species, reproductive biotechnologies are still not widely used by the breeders, largely due to traditional beliefs and past experiences showing low fertilization rates from AI.

In this study, only a few breeders acquired exotic males originating from Puno, Cusco, Huancayo, and Pasco regions to improve their livestock. The offspring (F1) of these bulls, rams, and male camelids were sold to local breeders. These breeders acquired the F1 generation because they lacked the logistical capacity to obtain purebred exotic males from other regions. AI in cattle was implemented only when there was government support, and the resulting offspring were frequently incorporated as breeding stock on their farms. Proper crossbreeding management ensures the efficient use of genetic resources and prevents inbreeding, which can deteriorate production traits (Nguluma et al., 2020). However, in the study areas, exotic breeds are introduced on the farm without any structured genetic improvement plan, undermining the prospects for a competitive livestock sector in the long term.

## Milking management

The availability of pasture is considered crucial for achieving substantial milk yields in this study. Some breeders carried out milking throughout the year, while others did so only during the rainy season. They selected the rainy period not only for milk production but also to secure the calves' survival, because pasture was sufficiently abundant at that time.

In this study, milking was generally done outdoors. Milk let-down in the cows is stimulated with the calves at their side, where the calves, with the milker's assistance, is allowed to pre-milk the four teats; the calf is then removed, and the milker begins to extract the milk. In other studies, calves were separated from their dams after receiving maternal care, including mucus removal and navel disinfection, a habitual practice in intensive livestock farms (Assefa et al., 2024). Some reports indicate that keeping the calf with the dam for 3 months results in greater weight gain, milk with lower fat content and higher protein levels, and a reduced risk of mastitis (Johnsen et al., 2016; Ospina et al., 2023).

## Shearing management

Currently, sheep wool has no market value in the region, and shearing is carried out only as part of reproductive management. The decline in wool prices in the domestic market is influenced by factors, including the central government's lack of interest and the absence of agricultural and promotional policies. These conditions have led to a deterioration in wool quality and a weakening of the wool value chain (Ardiles, 2024).

The market value of alpaca fiber is steadily increasing both nationally and internationally, to the extent that the Council of Fashion Designers of America (CFDA) now ranks alpaca as more sustainable than wool and cashmere. Despite this, the alpaca fiber production chain still presents numerous shortcomings. For example, in this study, the breeders do not have a specific space for shearing, and all the alpacas were sheared by hand, so there are generally losses, resulting in only about 5 pounds of fiber per animal produced. The fiber production chain also varies across different regions of Peru, highlighting the need to incorporate modern technologies at every stage of the production process (Mamani-Cato et al., 2024).

### Healthcare management

Although the livestock in this study were reported to be affected by some diseases, livestock in other regions of the world are found to be affected by a wide range of pathological conditions. Among ruminants, trypanosomiasis, foot-and-mouth disease, pasteurellosis, blackleg, mastitis, lumpy skin disease, rabies, tick infestations, brucellosis, and fascioliasis have been reported as the most prevalent health problems (Assefa et al., 2024).

In the study areas, breeders applied resilient health practices on their farms, which require the active involvement of entities such as the state and private companies, whose professionals can improve the sanitary management of the farm. Although breeders can act as health promoters, they lack sufficient training, which can compromise animal welfare. The limited access to specialized veterinary services observed in this study was mainly associated with the implementation of short-term publicly funded projects.

The livestock antiparasitic treatments, administered 1 to 4 times per year, were comparable to deworming practices in sheep, goats, cattle, and camelids reported in other parts of the country (Hinojosa et al., 2019; Poma et al., 2021; Palomino-Guerrera et al., 2024; Casas, 2023). Nonetheless, targeted selective treatment (TST) is now being applied, in which only those animals confirmed to be parasitized are treated (Bath and van Wyk, 2009).

## Marketing

For many rural households, raising livestock is a key economic activity and is even viewed as a form of "savings" that provides security for the future (Missohou et al., 2016; Manirakiza et al., 2020). In this research, cattle, sheep, and camelid farming represented the primary economic support for the families. Unlike breeders in Ancash (Poma et al., 2021), the breeders in this study had an established market for selling live lambs.

Factors such as limited accessibility, challenges in the production process, land expansion, and the weak organization of breeders indicate a short production chain in the livestock sector (Camara et al., 2019; Sow et al., 2021). Intermediaries are commonly the actors who obtain the highest profits within this chain; in response to this, Llave Arce et al. (2023) proposed the implementation of a collaborative model that establishes a direct agreement with the breeder, thereby removing intermediaries.

The breeders in this study did not engage with banks because the interest rates offered were too high. This contrasts with findings from other regions, where breeders were more inclined to work with banks (Salamanca et al., 2018; Casas, 2023). In many areas, banks have played a crucial role in supporting the expansion of the livestock sector; however, such opportunities are not available to small-scale husbandry, which lacks sufficient capacity and remains largely invisible in the value chain (Laouadi et al., 2018).

## Production system classification

Through multivariate analysis (MCA), breeders were classified according to three distinct groups of livestock farms. Farm size, grazing management, pasture types, origin of the breeding animals, and access to veterinary services were the factors that determined this classification. Understanding the typological dynamics of livestock systems is essential, as these systems are inherently dynamic (Giller et al., 2011).

The first group of breeders owned plots of land, both small and large, where camelids and sheep were the main animals grazing on vast expanses of natural pastures belonging to the breeders themselves and to the community. They raised cattle solely to ensure food security for their families. Their livestock grazed continuously throughout the year on their lands, where there were no rotational grazing systems or calculations of grazing time. The grazing areas lacked irrigation; the geography itself made water inaccessible, and they depended exclusively on the rainy season. Reproductive management was very poor, with no breeding plan, which directly affected the animals' productive capacity. In addition, the breeders themselves performed veterinary procedures to manage the health of their livestock. These veterinary practices may contribute to the misuse of medications and lead to disease resistance; furthermore, this lack of veterinary care may be linked to the fact that livestock are raised in remote areas where professionals and facilities are not always available.

In the second group, breeders owned large tracts of land, which were used to graze camelids, sheep, and cattle; these three species were their main source of income. Camelids and sheep mainly consumed natural pastures, while cultivated pastures were reserved for cattle; this is a common practice among many ranchers in this region because crossbred cattle are more demanding in terms of forage consumption. These breeders have effectively divided their pastures for their livestock to improve soil quality and forage availability. Where there was access to water, whether from a dam, rivers, springs, or ponds, ranchers cultivated companion forage crops or forage oats. These breeders managed their breeding programs more effectively by acquiring and rotating bulls in their farms, with the aim of improving production metrics on their farms.

In the third group, cattle were the mainstay of the family economy, followed by sheep and alpacas. Producers owned medium-sized pastures, most of which were cultivated. Most of the land had access to water, allowing ranchers to easily grow forage and oats, and all cultivated or natural areas were equipped with sprinkler or gravity irrigation systems. The livestock in this group made better use of the pastures because producers had divided their paddocks and, to maintain productivity, especially of their cattle, moved them to other sectors during a specific time of year. On their farms, they used breeding stock from different parts of the country and managed a controlled breeding program, either through natural mating in sheep and alpacas or through artificial insemination in cattle. The purchase of breeding stock was influenced by the breeders purchasing power and the lack of road access to the farms; in addition, they sought advice to improve the health standards of their farms.

The first group of breeders used continuous grazing for their livestock and had both large and small areas of natural pasture that lacked water access. In contrast, groups 2 and 3 employed both rotational and continuous grazing, providing their cattle with a variety of natural and cultivated pastures, all supplied with water through gravity-fed or sprinkler irrigation systems. Breeders in group 1 used males originating from their own farm or from the local region. In contrast, breeders in groups 2 and 3 incorporated males from other regions and used imported genetic material. Breeders in groups 1 and 2 personally attended to the health problems of their animals, unlike those in group 3, who at least sought assistance from animal health professionals.

There are no records of previous studies on the classification of mixed livestock farms in this country. In the regions of Ayacucho, Lima, and Tumbes, three groups of farming systems were identified in goats (Palomino-Guerrera et al., 2024; Paredes Chocce et al., 2024; Temoche et al., 2025), and four and six groups of farming were also reported (Ayala et al., 2024; Sessarego et al., 2025).

This classification of livestock farms demonstrates the heterogeneity of the breeding systems that exist in the study sectors. In this study, three groups of livestock systems were found, which constitutes key information to be able to develop competitive livestock farming in the region. The regional government, based on this qualification, which details the limitations and strengths of each group, can implement specific livestock projects that are sustainable and reflect the improvement of the quality of life of medium and small breeders in the region. Classifying livestock farms is a pilot tool for tailoring policies and interventions to the diverse types of livestock production systems (Ripoll-Bosch et al., 2014).

In the Peruvian Andes, traditional livestock breeding involves keeping multiple animal species within the same farm to ensure family food security and economic livelihoods. Nevertheless, the high diversity of these mixed livestock farms makes them difficult to characterize and understand. Grouping farms seeks to establish relatively homogeneous systems, particularly in terms of their socioeconomic and productive characteristics. Moreover, the geographic features of each region or country, together with social, cultural, and economic parameters, are likely to have shaped the different livestock production systems (Palomino-Guerrera et al., 2024). Rather than focusing solely on present environmental and socioeconomic issues, it is necessary to identify and describe the different systems and develop specific strategies to optimize them at the sectoral level (Ayala et al., 2024).

In research focused on characterizing production systems, it is recommended to conduct longitudinal studies that take into account the generational interval of the production chain, socioeconomic conditions, and the various actors involved in the value chain. Studies of this type make it possible to gain a comprehensive understanding of the system used in a particular sector. At present, in the sectors analyzed, livestock policies do not adequately reflect the diversity of existing systems when designing public investment projects, which hinders efforts to reduce existing gaps. In contrast, in other parts of the world, recognizing the presence of highly heterogeneous systems, specific policies are being implemented that are tailored to the prevailing breeding systems (Bartkowski et al., 2022; Stetter et al., 2022; Benitez-Altuna et al., 2023).

# Conclusion

The study demonstrates that livestock breeders in south-eastern Peru raise cattle, sheep, alpacas, and llamas in remote areas characterized by limited physical accessibility and scarce basic services. Livestock production constitutes their principal source of monetary income and represents a central component of household food and nutritional security.

Nevertheless, the livestock production chain is affected by multiple structural and technical limitations; these include weak systems for technology transfer and extension, chronic deficits in forage availability, suboptimal grazing management practices, mainly in sheep and camelids, and inadequate facilities for production and transport. In addition, milking and shearing are generally carried out with outdated technologies, while the high prevalence of infectious and parasitic diseases is exacerbated by restricted access to veterinary services. Finally, the marketing of animal products is hindered by significant logistical, organizational, and commercial barriers.

Three distinct groups of mixed livestock systems units were identified, where the first group exhibits a higher demand for technical support in reproductive and farm-management practices; the second group requires substantive potential for the development and expansion of commercial livestock production; and the third group is characterized by comparatively greater potential for competitive and market-oriented livestock farming.

This typology is primarily based on housing system, landholding size, feeding regime, feed source, and access to veterinary services. Such a classification framework for breeders can serve as a base for local governments to design targeted and appropriate interventions for mixed livestock production systems, in contrast to current generalized livestock development plans that overlook the heterogeneity.

# Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

# Ethics statement

Ethical approval was not required for the studies involving humans because for the preparation of this study, previously collected information from three planned investigations was used. From the information, those who practiced mixed livestock farming were selected to prepare this manuscript. Previous research aimed at characterizing the cattle production system, the sheep production system, and the camelid production system laid the groundwork for this study. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

## Author contributions

WP-G: Conceptualization, Methodology, Investigation, Formal analysis, Software, Data curation, Validation, Writing – original draft, Writing – review and editing. HG: Conceptualization, Methodology, and Investigation. MC: Validation, Supervision, Resources, Project administration, and Funding acquisition. FT: Validation, Review and editing. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Generative AI statement

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## Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontierspartnerships.org/articles/10.3389/past.2026.16335/full#supplementary-material

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