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Characterization of goat production systems in the Amazonian dry tropical forest of Peru through multivariate analysis

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The study aimed to characterize goat production systems in the tropical dry forest of Peru through multivariate analysis of 25 socioeconomic and productive variables in 60 producers from Bagua Grande, El Milagro, Cajaruro, and Cumba. Descriptive analysis, multidimensional scaling (stress = 0.03272), categorical principal component analysis (CATPCA), and hierarchical clustering analysis (HCA) were applied. A predominance of extensive management (98.3%), with low technical assistance (81.7%), absence of irrigation (90%), and visual selection of animals (100%) was identified. Marketing responds to immediate economic needs (36.7%), while vaccination coverage is poor (88.3% not vaccinated). CATPCA explained 54.5% of the variance (Cronbach's alpha = 0.965), highlighting producer education, infrastructure, and access to water and energy as key factors for improving production efficiency and mitigating commercial seasonality. HCA identified two goat production systems: the improved extensive system (EES) and the traditional extensive system (TES). The EES grouped older and more experienced producers, with larger herds, higher sales weights, greater specialization, forage diversification, better infrastructure, and higher deworming frequency. In contrast, the TES included younger producers with smaller herds, lower sales weights, lower educational levels, agricultural dependence, less forage diversity, limited infrastructure, and limited sanitary measures. These differences highlight the impact of knowledge and technological development on productive sustainability. It is concluded that technological development, access to resources, and production experience are key to improving the efficiency and sustainability of goat systems in the tropical dry forests of Peru.

KEYWORDS

typification, goat farming, multivariate analysis, agricultural sustainability, dry tropical forest

Introduction

Goat production is a strategic activity for Peru's rural economy, especially in fragile ecosystems such as the tropical dry forest of Utcubamba province. This territory, which includes the districts of El Milagro, Bagua Grande, Cajaruro, and Cumba, has particular agroecological conditions that make production systems highly dependent on natural resources and local knowledge (Uhlenbrock and Rodríguez, 2005). On the northern Peruvian coast, goat farming is mostly developed under extensive schemes, with grazing in dry wooded areas and an orientation focused on the production of kids for meat (Sarria et al., 2014).

Characterizing these production systems is essential to understanding their structure, dynamics, and main limitations. In this context, multivariate analysis is positioned as a robust methodological tool for identifying hidden patterns in complex data sets, segmenting production units, and recognizing typologies based on socioeconomic and productive variables. Previous studies have demonstrated its usefulness in differentiating between traditional subsistence systems and systems with higher levels of technification, generating key inputs for decision-making at the technical and political levels (Barboza et al., 2020b; García-Bonilla et al., 2018).

In the Utcubamba tropical dry forest, there is presumably a high degree of heterogeneity in management practices, access to services, levels of capitalization, and marketing strategies, which suggests the existence of multiple productive typologies. Identifying this diversity is fundamental to formulating differentiated interventions that promote the sustainability and profitability of goat systems, considering variables such as the educational level of producers, the size of productive units, land tenure regime, and access to infrastructure and technical assistance (Sarria et al., 2014; García-Bonilla et al., 2018).

In addition to their productive and social value, the characterization of these systems can contribute to the conservation of the tropical dry forest ecosystem by promoting practices that integrate environmental sustainability and economic viability. Evidence indicates that the design of public policies adapted to the specific conditions of each group of producers increases the efficiency of agricultural extension programs and improves the living conditions of rural communities (García-Bonilla et al., 2018).

The research aimed to characterize goat production systems in Peru's tropical dry forests through multivariate analysis, considering socioeconomic and productive indicators.

Materials and methods

Study area

The study was conducted in the districts of Bagua Grande, El Milagro, Cajaruro, and Cumba, Utcubamba province, Amazonas region, Peru (Figure 1). Utcubamba, located in the northeastern part of the country, covers 3,859.93 km^2, equivalent to 9.83% of the regional territory.

The geography of these districts varies from lowland areas, such as El Milagro (400 masl) and Bagua Grande (440 masl), to higher elevations such as Cumba (504 masl). Cajaruro, the largest district (1,763.23 km^2, 45.68% of the province), has a diverse topography that influences goat production.

The climate varies according to altitude. In the low areas (400–1,400 masl), it is warm, with temperatures up to 40 °C and annual rainfall of 1,300 mm. At higher altitudes (1,400–2,900 masl), it is temperate, with temperatures ranging from 14 °C to 25 °C and annual rainfall between 500 and 3,500 mm. These environmental conditions determine goat management strategies in the region (SENAMHI, 2019).

Sample and data collection

A sample of 60 goat producers was selected, corresponding to 48% of the total registered producers in the area (INEI, 2012). The sample was distributed proportionally according to the number of producers per district: El Milagro (28; 46.7%), Bagua Grande (13; 21.7%), Cajaruro (8; 13.3%), and Cumba (11; 18.3%). The gender composition was balanced, with 31 women (51.7%) and 29 men (48.3%).

The selection was carried out using non-probability discretionary sampling, seeking to adequately represent the heterogeneity of goat production systems in the different districts. This approach made it possible to consider the socioeconomic and productive specificities of each locality, ensuring the collection of reliable and statistically robust data.

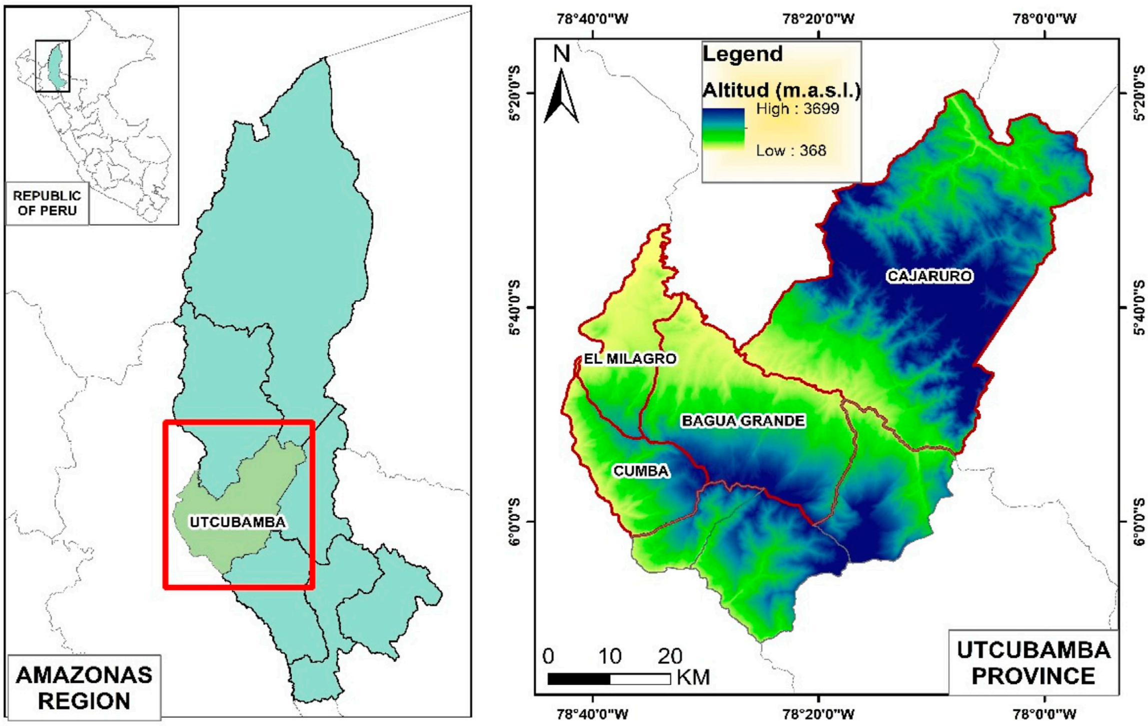

FIGURE 1
Geographical location of the study area.

Classification and treatment of variables

The selected variables were grouped into three components: socioeconomic, productive, and economic. Variable reduction process was carried out using the PROXSCALE optimal scaling procedure in SPSS Statistics v27, selecting those with greater Euclidean distances. Five scalar, seven ordinal, seven nominal, and six binary variables were included (Table 1), which made it possible to adequately capture the structural complexity of the goat systems in the study area.

Using SPSS Statistics version 23 software, variables were selected using the PROXSCALE optimal scaling procedure. Variables with the greatest Euclidean distances were grouped into socioeconomic and productive components to identify patterns in goat production systems. The variables were grouped into 5 scalar components, 7 ordinal components, 7 nominal components, and 6 binary components (Table 1).

Using categorical principal component analysis (CATPCA) and hierarchical clustering analysis (HCA), dimensionality was reduced, and two types of production systems were identified: Cluster 1, representing the traditional extensive farming system (TEF), and Cluster 2, associated with the improved extensive farming system (EES). Both systems are described in detail in the results and discussion section.

Statistical analysis

The analysis included descriptive analysis, CATPCA, and HCA. Data were processed using SPSS Statistics 23. Mean and percentage frequencies of descriptive variables were calculated, and CATPCA with multidimensional scaling with Varimax rotation and Kaiser normalization was applied. Nine dimensions were identified that explained 54.45% of the accumulated variance, with a Cronbach's alpha of 0.965.

HCA was performed in RStudio V4.4.1 using the tidyverse, cluster, factoextra, and NbClust libraries (R Core Team, 2023) with information from the nine dimensions for the 60 producers. Homogeneous groups were identified, and a dendrogram was generated based on Euclidean distance and the complete linkage method ($k = 2$, $n = 60$). The distribution of clusters was represented graphically to characterize the production systems.

To verify the existence of significant differences between the two clusters, nonparametric statistical tests were applied: the Mann-Whitney U test for scalar variables and the chi-square test of independence for categorical variables, considering a significance level of $p < 0.05$. These analyses made it possible to identify contrasting patterns in the organizational and functional structure of goat production systems, providing empirical evidence for their differentiated characterization in the context of the region studied.

TABLE 1 Classification of variables used in the analysis of social, productive, and economic factors in goat raising in Amazonas.

Component	T	Variables	Categories and/or units
Economic	S	Age of those driving the property	Years
	O	Farmer's level of education	No education, incomplete primary, complete primary, incomplete secondary, complete secondary, complete higher education
	S	Family members per household	Number
	B	Access to electricity	Yes/No
	N	Source of income	Agriculture, livestock, commerce
	O	Monthly household income (S/.)	Less 500, 501 to 1,000, 1,001 to 2000
	N	Month of sale	January– March, April– June, July– September, October–December
	O	Age of sale	1–3 months, 4–8 months, over 9 months
	S	Sales weight of the goat	Kg
	N	Reason for raising	For family tradition, for being a breeding area, for low investment, for market for sale, and for other reasons
Productive	O	Land area (ha)	<0.5, 0.5–2.0, >2.0
	O	Rearing area (ha)	<1.0, 1.0–2.0, >2.0
	B	Access to irrigation system	Yes/No
	B	Performs mixed breeding	Yes/No
	O	Aging time (years)	<5, 5–10, 11–20, >20
	N	Productive breeding months	January– March, April– June, July– September, October–December
	O	Dedication to parenting (hours)	<3, 3–6, >6
	S	Goat herd size	Number
	S	Goat population	Number
	N	Preferred forage shrub	Huarango (Prosopis pallida), huarango and carob (Vachellia macracantha), faique or tara (Caesalpinia spinosa) and carob, endemic cactus (Weberbauerocereus weberbaueri)
	N	Month of calving	January– March, April– June, July– September, October–December
	N	Installation type	Only corrals, corrals and sheds, corrals and others
	B	Corrals shared with other species	Yes/No
	B	Perform deworming	Yes/No
	B	Technical assistance received	Yes/No

Note: T = variable type; O = ordinal; N = nominal; E = scalar; B = binary. The goat population ranged from 8 to 160 animals. According to the INEI (2012), the goat population in the area was 2,616.

Result

Descriptive analysis

The socioeconomic and productive characterization of goat farmers in Amazonas reveals a rural context with limited structural conditions. Female participation predominates (51.7%) in the 35–45 age range (39.1%), with a low level of education, incomplete primary school being the most common (33.3%). Households are made up of 4–5 members (51.7%), and, in 80% of the cases, productive decisions are made by the parents. In addition, 55% of those surveyed report less than 5 years in the activity, which suggests a recent insertion in goat raising.

In terms of basic infrastructure, 60% of households have electricity, and 68.3% live in adobe houses. Monthly household income fluctuates between S/550 and S/1,000 in 70% of the cases,

TABLE 2 Explained variance and communalities of the principal components.

C	Variable	Dimensions									Community
		D1	D2	D3	D4	D5	D6	D7	D8	D9	h^2
Socio-economic	Age of producers	0.607	−0.195	0.002	−0.171	−0.098	−0.187	−0.157	−0.058	0.298	0.597
	Level of education	−0.278	0.167	−0.779	0.003	−0.114	0.095	−0.044	−0.049	−0.143	0.758
	Family members	0.009	−0.277	0.143	0.039	0.694	−0.236	−0.163	−0.118	−0.106	0.688
	Electric power	0.317	−0.168	0.410	0.312	−0.278	0.019	0.022	0.090	0.163	0.507
	Source of Income (*)	0.641	0.210	0.045	0.390	0.272	0.326	0.268	0.476	0.170	0.124
	income	0.080	−0.006	−0.432	−0.208	0.402	−0.411	−0.049	0.184	−0.181	0.636
	Month of sale (*)	0.138	0.341	0.315	0.607	0.469	0.521	0.237	0.660	0.517	0.206
	Age of sale	−0.162	0.157	0.362	−0.591	0.122	−0.126	−0.172	0.055	−0.005	0.595
	Sales weight	0.008	−0.086	0.009	0.865	−0.006	−0.078	0.005	0.099	0.002	0.772
	Reason for raising (*)	0.401	0.283	0.742	0.382	0.355	0.257	0.423	0.520	0.173	0.179
Productive	Area of the property	0.300	0.088	0.204	0.033	−0.176	−0.045	0.211	−0.079	0.502	0.477
	Breeding area	0.079	0.126	0.014	−0.087	0.622	0.119	−0.070	0.264	−0.027	0.506
	Irrigation system	0.072	−0.093	0.750	−0.255	0.066	0.248	−0.064	−0.012	−0.039	0.712
	Mixed breeding	−0.077	0.895	−0.111	−0.116	−0.055	−0.055	−0.092	0.107	0.031	0.859
	Parenting time	0.757	−0.116	0.171	−0.236	0.103	0.040	0.153	−0.221	−0.115	0.769
	Months of raising (*)	0.077	0.525	0.239	0.533	0.321	0.623	0.421	0.528	0.432	0.195
	Time dedicated to goat rearing	0.423	−0.136	0.133	−0.074	−0.047	0.652	−0.200	−0.148	−0.124	0.726
	Herd size goats	0.830	0.065	0.112	0.267	0.080	0.192	0.117	0.023	0.082	0.840
	Goat population	0.801	0.036	0.117	0.289	0.035	0.187	0.103	0.069	0.147	0.813
	Preferred shrub (*)	0.333	0.458	0.192	0.404	0.689	0.321	0.501	0.607	0.310	0.202
	Month of calving (*)	0.122	0.105	0.292	0.579	0.152	0.660	0.628	0.100	0.496	0.173
	Facilities (*)	0.462	0.179	0.190	0.268	0.570	0.333	0.148	0.224	0.661	0.144
	Shared corrals	−0.008	0.903	−0.114	−0.087	−0.004	−0.014	−0.062	0.118	0.012	0.854
	Deworming	−0.136	0.352	0.056	0.132	0.200	−0.170	−0.108	0.660	−0.077	0.684
	Technical assistance	0.119	−0.142	−0.017	0.080	−0.161	−0.082	0.713	−0.072	0.094	0.596
Total eigenvalue		3.737	2.802	2.683	3.126	2.615	2.387	1.911	2.334	1.800	13.613
Variance (%)		14.949	11.209	10.733	12.502	10.460	9.546	7.645	9.334	7.199	54.452

(*) The estimated saturations of the multiple nominal variables are not considered the sign.

although only 36.7% depend economically on livestock farming as their main activity. Technical assistance coverage is low (81.7% do not have access), which limits the incorporation of technological improvements.

The predominant system is extensive (98.3%), based on traditional knowledge (46.7%). Ninety percent of the farms do not have irrigation systems, and 73.3% use corrals. The main fodder species used is ryegrass (30%). In terms of animal management, 95% do not use identification methods, and 100% visually select the animals. Sales are mainly motivated by economic needs (36.7%).

Sanitary practices are limited: 88.3% do not vaccinate and only 10% carry out annual deworming. Sales tend to take place after 6 months (23.3%), which indicates a system with low technification. These findings demonstrate the need to strengthen technical assistance and integrated management to improve the efficiency and sustainability of the goat system in Amazonas.

TABLE 3 Comparison of quantitative socioeconomic and productive variables between groups of producers in goat production systems.

Components	Scalar variables	SEM (cluster 1)		SET (cluster 2)		U-mann whitney
		Average	Median	Average	Median	p-value
Economic	Age of producers	53.29 ± 2.94	52.0[a]	44.04 ± 2.77	39.5[b]	0.04051*
	Family members	3.65 ± 0.26	4.0[a]	3.62 ± 0.21	4.0[a]	0.8844
	Sales weight	14.23 ± 0.46	15.0[a]	12.88 ± 0.61	10.0[b]	0.05082*
Productive	Herd size goats	46.79 ± 7.68	25.0[a]	21.58 ± 2.38	18.0[b]	0.01061*
	Goat population	17.76 ± 3.36	8.0[a]	7.96 ± 0.98	6.5[a]	0.1056

SEM, improved extensive system; SET, traditional extensive system. Avg., mean; S.D., standard deviation. a, b, Medians within the same row with different superscripts differ significantly ($p < 0.05$).

Categorical principal component analysis (CATPCA)

CATPCA allowed the identification of underlying structures between the socioeconomic and productive variables in goat breeding (Table 2). Nine dimensions (D) were extracted, which together explain 54.5% of the total variance of the model. Internal consistency was high (Cronbach's $\alpha = 0.9655$), supporting the reliability of the results.

Socioeconomic component

From the socioeconomic level, CATPCA explained 37.2% of the accumulated variance, highlighting the influence of the educational and economic level of the producers. The variables with the highest communality were educational level (−0.779 in D3, $h^2 = 0.758$) and monthly income (−0.432 in D3, $h^2 = 0.636$), showing the relationship between education and income. Sales weight showed high association with D4 (0.865, $h^2 = 0.772$), highlighting its importance in marketing and income generation of producers.

Production component

In the productive component, key variables included irrigation system, mixed rearing, rearing time, hours of dedication, goat population, and shared pens, explaining 52.2% of the total accumulated eigenvalue. Mixed breeding (0.895 in D2, $h^2 = 0.859$) and shared pens (0.903 in D2, $h^2 = 0.854$) presented the highest saturations, while herd size (0.830 in D1, $h^2 = 0.840$) and goat population (0.801 in D1, $h^2 = 0.813$) were determinant in D1.

Dimensional analysis

The dimensional analysis revealed patterns linked to productive practices and socioeconomic aspects:

D1: Associated with herd size, goat population, and income diversification, indicating that more experienced producers tend to manage larger herds.

D2: Relates mixed breeding and shared pens, reflecting strategies oriented to diversification of production.

D3: Links the irrigation system, access to energy, and the reason for rearing inversely to the level of education and monthly income, indicating that those with less education and income apply more technological practices.

D4: Related to age and sales weight, highlighting the relevance of these variables in commercial dynamics and profitability.

Hierarchical cluster analysis (HCA)

HCA identified two clusters of producers, compared socioeconomically and productively (Tables 3–5; Figures 2, 3).

Analysis of the socioeconomic and productive component of quantitative variables

Table 3 shows significant differences ($p < 0.05$) between the two identified clusters. Cluster 1, called the improved extensive system (SEM), is composed of older producers (53.29 ± 2.94 years) compared to the traditional extensive system (SET, Cluster 2; 44.04 ± 2.77 years; $p = 0.04051$). No differences were observed in the size of the family nucleus ($p = 0.8844$), suggesting that this variable does not directly influence productive decisions.

SEM producers manage significantly larger goat herds (46.79 ± 7.68 vs. 21.58 ± 2.38; $p = 0.01061$) and achieve higher sale weights (15.0 kg vs. 10.0 kg; $p = 0.05082$). However, the number of goats in production did not differ between the two groups ($p = 0.1056$).

Analysis of socioeconomic and productive component of categorical variables

Table 4 shows differences in categorical socioeconomic variables. SEM has a higher educational level, with 5.9% having higher education ($p = 7.399E-04$). In addition, in this group, livestock is the main source of income (47.1%), while in the SET, agriculture predominates (73.1%; $p = 2.574E-05$). These differences reflect divergent economic and productive strategies.

TABLE 4 Comparison of categorical socioeconomic variables between producer groups in goat production systems.

Variables	Categories	SEM (cluster 1)		SET (cluster 2)		Chi-square
		n	%	n	%	p-value
Level of education	No education	5	14.7	1	3.8	7.399E-04***
	Incomplete elementary school	8	23.6	12	46.2	
	Completed elementary school	6	17.6	3	11.5	
	Incomplete high school	6	17.6	4	15.4	
	High school completed	7	20.6	6	23.1	
	Superior complete	2	5.9	0	0.0	
Electric power	Yes	22	64.7	14	53.8	0.116748494
	No	12	35.3	12	46.2	
Source of Income	Agriculture	14	41.2	19	73.1	2.57448E-05***
	Trade	4	11.7	1	3.8	
	Livestock	16	47.1	6	23.1	
Monthly income	0–500	7	20.6	6	23.1	0.10749719
	501–1,000	23	67.6	19	73.1	
	1,001–2000	4	11.8	1	3.8	
Month of sale	January–March	3	8.8	1	3.8	6.2468E-10***
	April–June	8	23.5	14	53.9	
	July–September	7	20.6	9	34.6	
	October–December	16	47.1	2	7.7	
Age of sale	Between 1 3 months of age	9	26.5	8	30.8	0.211109499
	Between 4 and 9 months of age	18	52.9	15	57.7	
	Over 9 months old	7	20.6	3	11.5	
Reason for raising	My area is dedicated to this type of breeding	7	20.6	10	38.5	0.000978488***
	Family tradition	18	53.0	14	53.9	
	Requires little investment	3	8.8	1	3.8	
	Other reasons	6	17.6	1	3.8	

Note: n: number of observations; SEM: enhanced extensive system; SET: traditional extensive system; (***) p-value <0.001.

Marketing patterns also vary: SEM sells goats mainly between October and December (47.1%), probably associated with seasonal demand, while SET sells goats between April and June (53.9%; p = 6.247E-10). Motivation for breeding differs: in SEM, family tradition predominates (53.0%), and in SET, the influence of the local environment (38.5%; p = 0.000978).

No significant differences were found in access to electricity (p = 0.1167), monthly income (p = 0.1075), or age at sale of animals (p = 0.2111).

Table 5 compares categorical productive variables, showing significant differences (p < 0.01). SET manages smaller farms, with 96.2% operating on less than 0.5 ha (p = 0.0041). In addition, they have less access to irrigation (3.8% vs. 14.7% in SEM; p = 0.0078) and practice mixed farming to a greater extent (84.6% vs. 58.8% in SEM; p < 0.001).

SET producers have less experience, with 65.5% registering less than 5 years (p < 0.001), while in the SEM there is a predominance of more than 20 years (26.5% vs. 11.5% in SET). In addition, SET spent less time on parenting (53.9% between 3 and 6 months), while in SEM 52.9% spent between 6 and 9 months (p < 0.001).

Differences in management are notable. SET depends mainly on huarango (*Prosopis pallida)* as a forage resource (92.3% vs. 55.9% in SEM; p < 0.001), while SEM diversifies with faique and

TABLE 5 Comparison of categorical productive variables between goat production systems.

Variables	Categories	SEM (cluster 1)		SET (cluster 2)		Chi-square
		n	%	n	%	p-value
Area of the property	<0.5 ha	28	82.4	25	96.2	0.004150906**
	0.5–2 ha	2	5.8	0	0.0	
	>2 ha	4	11.8	1	3.8	
Breeding área	<1 ha	4	11.8	1	3.8	0.100877276
	1–2 ha	2	5.8	2	7.7	
	>2 ha	28	82.4	23	88.5	
Irrigation system	Yes	5	14.7	1	3.8	0.007808996**
	No	29	85.3	25	96.2	
Mixed breeding	Yes	20	58.8	22	84.6	5.1224E-05***
	No	14	41.2	4	15.4	
Parenting time	<5 years	16	47.1	17	65.5	0.000651954***
	From 5 to <10 years	4	11.7	5	19.2	
	From 10 to <20 years old	5	14.7	1	3.8	
	>20 years	9	26.5	3	11.5	
Months of parturition	January – March	6	17.6	8	30.8	0.019458991*
	April – June	13	38.3	9	34.6	
	July – September	8	23.5	7	26.9	
	October – December	7	20.6	2	7.7	
Time dedicated to goat rearing	<3	7	20.6	3	11.5	0.000381104***
	3 a 6	9	26.5	14	53.9	
	6 a 9	18	52.9	9	34.6	
Preferred shrub	Faique and carob	7	20.5	2	7.7	2.38275E-08***
	Huarango	19	55.9	24	92.3	
	Huarango and carob tree	4	11.8	0	0.0	
	Others	4	11.8	0	0.0	
Month of calving	January – March	4	11.8	0	0.0	3.66504E-06***
	April – June	17	50.0	9	34.6	
	July – September	10	29.4	16	61.6	
	October – December	3	8.8	1	3.8	
Facilities	Single pens	22	64.7	22	84.6	0.000117183***
	Unique corrals with shed	7	20.6	4	15.4	
	Corrals and other environments	5	14.7	0	0.0	
Shared corrals	Yes	19	55.9	22	84.6	9.0313E-06***
	No	15	44.1	4	15.4	
Deworming	Yes	9	26.5	2	7.7	0.000414376***

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TABLE 5 (*Continued*) Comparison of categorical productive variables between goat production systems.

Variables	Categories	SEM (cluster 1)		SET (cluster 2)		Chi-square
		n	%	n	%	p-value
	No	25	73.5	24	92.3	
Technical assistance	Yes	7	20.6	4	15.4	0.338530296
	No	27	79.4	22	84.6	

n: number of observations; SEM: enhanced extensive system; SET: traditional extensive system; (*) p-value <0.05; (**) p-value <0.01; (***) p-value <0.001.

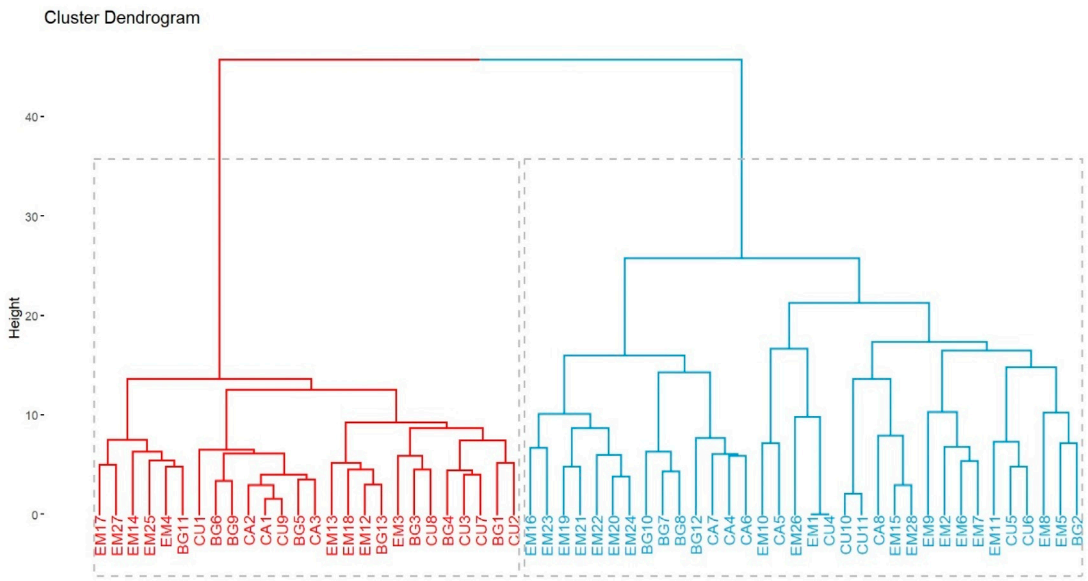

FIGURE 2
Hierarchical dendrogram of goat production systems in Amazonas based on Euclidean distance and complete linkage (k = 2, n = 60 producers).

carob (20.5%). In infrastructure, 84.6% of SET uses single pens, in contrast to SEM, where there is a greater variety of facilities ($p < 0.001$). In addition, SET uses more frequently shared corrals (84.6% vs. 55.9% in SEM; $p < 0.001$) and has a lower rate of deworming (7.7% vs. 26.5% in SEM; $p < 0.001$).

Seasonality of calving also varies. In SET, they predominate between July and September (61.6%), while in SEM they occur mainly between April and June (50%) ($p < 0.001$).

Socioeconomic and productive segmentation in goat systems (clusters)

HCA identified two clusters with differentiated characteristics: the improved extensive system (SEM) and the traditional extensive system (SET).

Cluster 1 (SEM) is made up of older (53.29 ± 2.94 years) and more experienced producers (26.5% > 20 years), with larger herds (46.79 ± 7.68 goats) and more goats in production (17.76 ± 3.36), although with higher sales weight (15 vs. 10 kg in SET). Livestock specialization predominates, the educational level is higher (5.9% with higher education), and livestock represents the main source of income (47.1% vs. 26.9% in SET). Marketing is concentrated between October and December, taking advantage of seasonal demand. Fodder is diversified (faique, carob, and huarango), and the infrastructure is more advanced, with a predominance of individual corrals. In addition, deworming is more frequent (26.5% vs. 7.7% in SET), and calving occurs mostly between April and June (50%).

Cluster 2 (SET) groups younger producers (44.04 ± 2.77 years) with less experience (65.5% < 5 years). Their herds are smaller (21.58 ± 2.38 goats), with fewer goats in production (7.96 ± 0.98) and lower sale weight (10 vs. 15 kg in the SEM). The educational level is lower (0% with higher education), and agriculture is the main source of income (73.1%). Sales are concentrated between April and June (53.9%). This system depends mainly on huarango as fodder (92.3% vs. 55.9% in SEM) and has less diversified infrastructure, with shared corrals

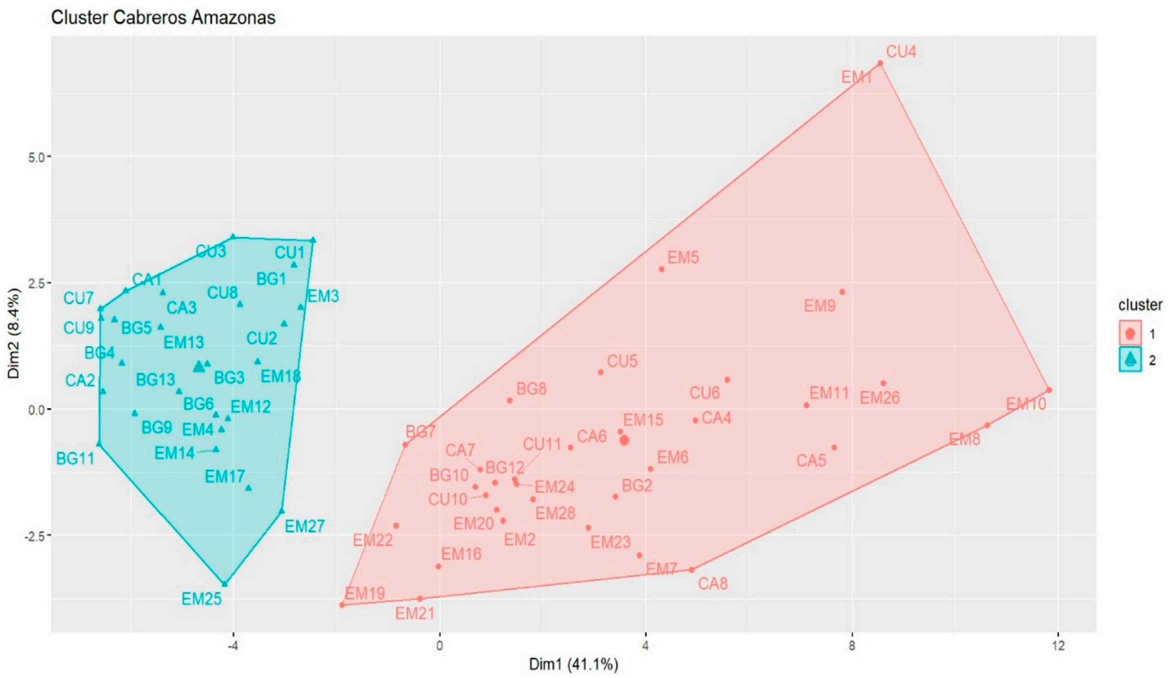

FIGURE 3
Distribution of clusters in the characterization of goat production systems in Amazonas.

predominating (84.6% vs. 55.9% in SEM). The implementation of sanitary measures is limited, with a low rate of deworming (7.7%), and calving occurs mainly between July and September (61.6%).

Discussion

Descriptive analysis

It was observed that 51.7% of the respondents were women, which contrasts with that reported by Marquínez-Batista et al. (2022) and Paredes et al. (2024), who documented a female participation of 27.4%. Concordantly, Sessarego et al. (2025) reported 56.1% male participation, while in studies conducted in Costa Rica and Brazil, Barboza et al. (2020a) and De Figueiredo et al. (2017) recorded even higher proportions of male participation (83.25% and 96.8%, respectively). Gispert-Muñoz et al. (2019) reported 78.3% male participation. These differences reflect how gender participation in goat production is determined by regional sociocultural, normative, and economic factors.

Regarding age, the predominant age group was 35–45 years (39.1%), in agreement with studies such as those of Ortiz-Morales et al. (2021) in Mexico, where an average of 48 ± 13 years was recorded, and Gökdai et al. (2020), who pointed out that this age distribution is typical in traditional goat systems. However, Sessarego et al. (2025) reported a higher average age (53.6 years), suggesting possible differences in the cycle of generational incorporation to the activity.

In terms of educational level, 33.3% of respondents presented incomplete primary school. This result falls between the findings of Laouadi et al. (2018), who reported 44.3% illiteracy in Algeria, and those of Sessarego et al. (2025), who reported 6.1% with no formal education. In Mexico, Ortiz-Morales et al. (2021) identified a predominance of basic education level, while Villacrees-Matias et al. (2017) found that 80% only attained primary education. Gispert-Muñoz et al. (2019) recorded a predominance of secondary level. These results show a low level of schooling among goat producers, which may limit the adoption of technologies and productive innovation.

About family structure, it was found that 51.7% of households consisted of 4–5 members, a result consistent with Escareño et al. (2011), who reported an average of 5.1 members. Villacrees-Matias et al. (2017) noted that 86% of households had children, with an average of four per family. Furthermore, in 80% of the cases, parents were responsible for productive decisions, supporting the presence of a traditional family management model (Palomino et al., 2024; Rodríguez-Vargas et al., 2022).

Finally, 55% of the respondents had less than 5 years of experience in goat farming, suggesting a recent incorporation process. In contrast, Ortiz-Morales et al. (2021) found that only 20% considered goat rearing as their main source of income.

Laouadi et al. (2018) identified that 37.7% assumed it as their main activity, while Escareño et al. (2011) and Gispert-Muñoz et al. (2019) reported its mixed use: family consumption (32.1%) and secondary activity (30.2%) (Sarria et al., 2014). These findings indicate that, although goat activity has diversified, a subsistence and complementary use approach still predominates in many rural contexts.

Principal component analysis categorical

Multivariate analysis made it possible to identify the most relevant qualitative variables in the characterization of goat production systems in the tropical dry forest of Peru. Through CATPCA, the number of variables was reduced from 71 to 25, which facilitated the evaluation of interactions between socioeconomic and productive factors, the identification of nine main dimensions, and the classification of two differentiated production systems. These results are in agreement with previous studies conducted in Peru (Sarria et al., 2014; Rodríguez-Vargas et al., 2022; Palomino et al., 2024; Sessarego et al., 2025; Temoche et al., 2025) and abroad (Gispert-Muñoz et al., 2019; González et al., 2017; Vázquez-Rocha et al., 2024; Villacrees-Matias et al., 2017; Delgado-Fernández, 2016; Laouadi et al., 2018; Valerio et al., 2009; Akounda et al., 2023).

CATPCA model identified nine dimensions that explain 54.5% of the total variance, demonstrating its ability to synthesize the complexity of goat systems. The high reliability of the model (Cronbach's alpha = 0.9655) supports the robustness of the findings. These results are consistent with those reported by Sarria et al. (2014) and Palomino et al. (2024), whose models explained between 45% and 85% of the variance, reflecting the inherent heterogeneity of socioeconomic and productive indicators. Despite this variability, all studies coincided in reporting high levels of reliability, in line with the present analysis.

The stability in the percentages of variance explained and the high values of Cronbach's alpha in various studies consolidate the usefulness of CATPCA as a tool for identifying key factors and production patterns in contexts of high environmental variability. Moreover, they reinforce its relevance for the design of strategies aimed at productive optimization and improving resilience to climate change (Delgado-Fernández, 2016; Laouadi et al., 2018; Valerio et al., 2009; Akounda et al., 2023).

Socioeconomic component

From a socioeconomic perspective, CATPCA explained 37.2% of the accumulated variance, identifying educational level and monthly income as determinant variables in goat production. The high communality of educational level (h^2 = 0.636) and monthly income (h^2 = 0.636) evidences their influence in the model, highlighting the catalytic role of education in technological adoption and the improvement of productive efficiency.

These findings are consistent with those reported by Sarria et al. (2014), Rodríguez-Vargas et al. (2022), Palomino et al. (2024), Sessarego et al. (2025), and Temoche et al. (2025), who directly link academic training and income with the sustainability of the goat sector. The negative association with dimension D3 indicates that low educational levels limit household income and investment capacity, which reinforces the need for public policies aimed at training and strengthening rural human capital. Pérez et al. (2019) argue that schooling facilitates technological adoption, although its implementation is still limited in certain contexts (Pérez and Larios-González, 2018).

Sales weight showed a high association with dimension D4 (0.865; h^2 = 0.772), reflecting its impact on marketing and income generation. Improving animal growth and access to markets is fundamental to increasing the competitiveness of the goat sector (Rebollar-Rebollar et al., 2012).

Production component

Productive component explained 52.2% of the total accumulated variance, with irrigation system, mixed rearing, rearing time, hours of dedication, goat population, and shared pens as significant variables. Mixed breeding (0.895 in D2; h^2 = 0.859) and shared pens (0.903 in D2; h^2 = 0.854) presented the highest saturations, followed by herd size (0.830 in D1; h^2 = 0.840) and goat population (0.801 in D1; h^2 = 0.813).

These results are consistent with Sarria et al. (2014), who identified mixed goat-bovine systems supported by agricultural by-products on the central coast of Peru. Other studies also document similar mixed breeding practices and shared use of facilities (Salamanca et al., 2018; Holanda et al., 2004; Grajales et al., 2011; Valerio et al., 2009). Palomino et al. (2024) reported that in Ayacucho 59% of farms combine sheep and goats in family systems.

Herd size has been widely recognized as a key factor in productive sustainability (Delgado-Fernández, 2016; Martinez et al., 2022; Sarria et al., 2014; Rodríguez-Vargas et al., 2022), supporting its relevance in the present study.

Dimensional analysis

D1 (Herd size and income diversification): This dimension reveals that producers with more experience tend to manage larger herds and diversify their income sources, which reinforces their economic stability. This pattern coincides with that reported by Escareño et al. (2011) in the Comarca Lagunera, Mexico, as well as with studies by Delgado-Fernández (2016), Martínez et al. (2022), Sarria et al. (2014), and Rodríguez-Vargas et al. (2022), who document the positive relationship between herd size and productivity.

D2 (Shared corrals and mixed breeding): Reflects strategies of efficient use of resources through shared housing and joint breeding of different species. Hernández-Hernández et al. (2014) describe this practice in the Mixteca Poblana, Mexico, highlighting the role of common infrastructure and family labor. Similar results have been reported by Salamanca et al. (2018), Holanda et al. (2004), Grajales et al. (2011), Valerio et al. (2009), and Palomito et al. (2024), highlighting its prevalence in rural settings and its contribution to the integral use of resources.

D3 (Technological adoption and socioeconomic profile): Evidence of a direct relationship between the use of basic technologies (irrigation, energy) and productive motives, as well as an inverse relationship with educational level and income. These findings suggest that producers with fewer resources adopt accessible technologies to improve efficiency and profitability, in agreement with Sharma et al. (2023) and Schneider (2016).

D4 (Age and selling weight): This dimension emphasizes that selling young kids at higher weights contributes to optimizing profitability, reducing feed costs, and adapting to market preferences (Mellado et al., 1991). Age and sale weight are determined by breed, production system, and demand. Arias et al. (2004) and Jiménez (2020) report growth trajectories in Costa Rica and Ecuador, respectively, that reflect differences according to the production environment. In Mexico, Mendoza et al. (2021) document differentiated prices according to the age and weight of the animals, which confirms the economic impact of this dimension.

D5 (Family labor and diversified diet): The availability of family labor and greater rearing area allows for diet diversification through the inclusion of native forages. Paz and Cardozo (2001), Camejo (2024), and Castel et al. (2012) agree that these factors improve food management and the sustainability of the system by facilitating greater adaptability and use of local resources.

D6 (Management of the reproductive cycle): Indicates intensive management aimed at productive continuity through practices such as synchronization of estrus, staggered calving, and the use of hormones. According to National Institute of Agricultural Technology (2024) and National Institute of Agricultural Research (2024), these strategies allow stabilizing milk and meat supply, increasing reproductive efficiency, and ensuring continuous production.

D7 and D8 (Sanitary management and technical assistance): Underline the importance of animal health and technical support to improve productivity. Deworming and technical training increase the efficiency of the system (Palomino et al., 2024; Temoche et al., 2025). In Córdoba, Argentina, Cáceres et al. (1998) link the use of deworming with technical assistance and farm size, while Caballero (2018) reports productive improvements derived from comprehensive animal health programs in Central America.

D9 (Infrastructure and productive efficiency): This dimension relates the quality of facilities and available surface area to key productive indicators. National Institute of Agricultural Technology (2024) highlights that adequate infrastructure improves feeding, sanitary management, and animal welfare, increasing efficiency. National Institute of Agricultural Research (2024) complements by pointing out that an optimal environment allows natural behavior and favors the sustainability of the system.

Hierarchical cluster analysis

HCA allowed the Amazonas goat producers to be segmented into two groups (k = 2) according to nine dimensions, using Euclidean distance and complete linkage. Two production systems were identified: the traditional extensive system (SET) (Cluster 1) and the improved extensive system (SEM) (Cluster 2). The Mann-Whitney U-test and chi-square test revealed significant differences in productive characteristics, linked to resource availability, feeding, and access to markets.

These findings are in agreement with previous studies (Sarria et al., 2014; Rodríguez-Vargas et al., 2022; Palomino et al., 2024; Sessarego et al., 2025; Temoche et al., 2025; Gispert-Muñoz et al., 2019; González et al., 2017; Vázquez-Rocha et al., 2024; Villacrees-Matias et al., 2017; Delgado-Fernández, 2016; Laouadi et al., 2018; Valerio et al., 2009; Akounda et al., 2023), which highlight how heterogeneity in production systems influences the efficiency and sustainability of the goat sector.

Identifying these patterns is key to designing differentiated strategies to optimize production and strengthen the competitiveness of the sector in the region. Implementing support and training policies adapted to each production system could improve the efficiency and sustainability of goat production in Amazonas.

In addition, Oliveira et al. (2022) and Laouadi et al. (2018) highlight the usefulness of multivariate approaches to classify productive systems according to their livestock integration, management, and objectives.

Analysis of the socioeconomic and productive component of quantitative variables

Comparative analysis of the socioeconomic and productive variables revealed significant differences between the SEM and SET systems. In SEM, producers presented a higher average age (53.29 ± 2.94 years) compared to SET (44.04 ± 2.77 years; $p = 0.04051$), suggesting a relationship between greater experience and adoption of improved practices. This pattern has been documented in studies such as those of Temoche et al. (2025), Palomino et al. (2024), Sessarego et al. (2025), and Gispert-Muñoz et al. (2019), who highlight the role of accumulated experience in improving productive efficiency. In a similar context, Bedotti (2000) points out that older producers in goat systems in the western Pampean region of Argentina apply more efficient management techniques, promoting more sustainable production.

Also, herds managed in the SEM are significantly larger (46.79 ± 7.68 goats) than in the SET (21.58 ± 2.38), as is the number of goats (17.76 ± 3.36 vs. 7.96 ± 0.98; $p = 0.01061$). In addition, the average sale weight of animals is higher in SEM (15 kg) compared to SET (10 kg; $p = 0.05082$), reflecting differences in feeding and management strategies. In traditional systems, reliance on extensive grazing on natural vegetation limits optimal animal growth, as evidenced by Barrera et al. (2018) in extensive goat farming in San Luis Potosí, Mexico.

On the other hand, the average family size did not show significant differences ($p = 0.8844$), suggesting that this variable does not directly influence production. However, greater age and experience in SEM translate into more efficient practices, which allow for larger herd size, although with a slight decrease in individual weight, in line with the findings of Escareño et al. (2011). This evidence highlights the need to balance quantity and quality to optimize the profitability of the activity.

Ocampo-Fletes and Escobedo-Castillo (2006) also highlight that, in regions such as the Mixteca and Central Valleys of Oaxaca, producers over 50 years of age retain traditional knowledge that favors herd adaptation and the development of sustainable strategies, reinforcing the importance of empirical knowledge as a basis for the incorporation of technological innovations.

Analysis of socioeconomic and productive component of categorical variables

Differences between SET and SEM systems were also significant in categorical variables ($p < 0.05$) related to specialization, education, income sources, marketing, motivations, infrastructure, experience, time of dedication, forage resources, health, and seasonality of calving.

In the SEM, a greater livestock specialization and a higher educational level are observed: 5.9% of the producers achieved higher education, compared to 0% in the SET ($p = 7.399E-04$). Several studies (Salas et al., 2013; Anzaldo-Montoya, 2020) argue that education facilitates the adoption of more efficient productive practices.

The main source of income in SEM is livestock (47.1%), while in SET agriculture predominates (73.1%; $p = 2.57448E-05$), reflecting differentiated economic strategies. In addition, animal commercialization presents a marked seasonality: in SEM it is concentrated between October and December (47.1%), and in SET between April and June (53.9%), probably influenced by climatic and market factors (Rizo-Mustelier et al., 2017; Barrera et al., 2018). This information is key to designing commercial strategies to boost demand for goat products, even in systems with limited infrastructure (Ripoll et al., 2024; Schneider, 2016).

In terms of motivations, family tradition predominates in the SEM (53.0%), while in the SET it is considered a common activity in the area (38.5%). Generational continuity is related to greater sustainability of the system (Hernández, 2000).

Infrastructure limitations are evident in SET: 96.2% of the farms have less than 0.5 ha, with little access to irrigation (3.8% vs. 14.7% in SEM; $p = 0.0078$), and a higher proportion of mixed farming (84.6% vs. 58.8%). These conditions restrict productive potential and hinder the implementation of technologies. Basic infrastructure and access to water are fundamental for the sustainability of the system (FAO, 2023; Pateiro et al., 2020; Martínez et al., 2022).

SEM producers also show greater experience: 26.5% have more than 20 years in the activity, while in the SET, 65.5% have less than 5 years ($p < 0.001$). The time of dedication is also greater in the SEM (52.9% between 6 and 9 months, compared to 53.9% between 3 and 6 months in the SET), which has an impact on better productive results (Aréchiga et al., 2008; Temoche et al., 2025).

Regarding forage management, SET relies mostly on huarango (92.3%), while SEM diversifies with faique and carob (20.5%), which provides greater resilience (Sarria et al., 2014; Contreras et al., 2023). Likewise, deworming is more frequent in SEM (26.5% vs. 7.7% in SET), reflecting better sanitary practices (Miranda-De La Lama and Estévez-Moreno, 2022). Limited identification and sanitary control in SET restrict access to specialized markets and increase vulnerability to adverse events (Laouadi et al., 2018).

Regarding reproductive seasonality, SET concentrates calving between July and September (61.6%), while SEM calves between April and June (50%). This difference may be due to reproductive strategies that seek to coincide with the greatest availability of resources, optimizing offspring survival (Mellado, 2008).

Socioeconomic and productive segmentation in goat systems (clusters)

The differences between SEM and SET reveal marked contrasts in technological adoption, resource management, and economic strategies. In SEM, producers with more experience and education focus on livestock specialization and diversify the use of forages, which translates into more developed infrastructures and a rigorous application of sanitary practices. These results are consistent with previous research linking education and experience with greater efficiency in goat management (Vázquez-Rocha et al., 2024; Ortiz-Morales et al., 2021; Maldonado-Jáquez et al., 2019; Temoche et al., 2025; Palomino et al., 2024).

In contrast, SET groups together younger producers with less experience, whose main source of income is agriculture and who operate with less technical management. The scarce forage diversification, limited infrastructure, and weak implementation of sanitary measures are associated with economic restrictions and less access to technical assistance. This pattern coincides with that reported for traditional goat systems in arid and semiarid regions of Latin America, characterized by conventional practices with little technological innovation (Ortiz-Morales et al., 2021; Maldonado-Jáquez et al., 2019).

In addition, the seasonality observed in marketing and lambing in both systems reflects an adaptive response to the availability of forage resources and local climatic conditions. These dynamics affect production planning and market strategies, so understanding them is essential for designing policies that promote the sustainability and profitability of goat production (Rebollar-Rebollar et al., 2012; Sessarego et al., 2025).

Conclusions

Socioeconomic and productive variables explained 54.5% of the variance, showing that the sustainability of goat production in Amazonas depends on producer education, infrastructure availability, and access to water and energy resources, determining factors for optimizing productive efficiency and mitigating seasonality in marketing.

The cluster analysis identified two goat production systems: the improved extensive system (SEM) and the traditional extensive system (SET). SEM brings together older and more educated producers with larger herds, greater forage diversification, better infrastructure, frequent sanitary practices, and reproductive planning, with lambing between April and June. In contrast, SET groups less experienced producers with smaller farms, limited access to irrigation, and mixed breeding, where huarango predominates as fodder. In addition, goat activity is secondary, the corrals are rudimentary, deworming is sporadic, and lambing occurs mostly between July and September.

Data availability statement

The authors acknowledge that the data presented in this study must be deposited and made publicly available in an acceptable repository, prior to publication. Frontiers Publishing Partnerships cannot accept a manuscript that does not adhere to our open data policies.

Author contributions

AR-V: Data Analysis, intrepretation, manuscript writing. LT-G: Conceptualization, Design of study, Investigation, visualization. ES: Data Analysis, interpretation, manuscript review and editing. GA: Design of study, Investigation, visualization. KC-P: Investigation, traduction, manuscript writing, review and editing. JH-R: Intrepretation, traduction, manuscript review and editing. JR-C: Conceptualization, manuscript writing, review and editing. CB-C: Manuscript review and editing. JC: Conceptualization, manuscript review and editing, supervision.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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