Journal of Agriculture, Food, Environment and Animal Sciences
Tarım, Gıda, Çevre ve Hayvancılık Bilimleri Dergisi
http://www.jafeas.com, ISSN: 2757-5659

J. Agric. Food,
Environ. Anim. Sci.
6(2): 488-509, 2025

AI-Assisted Assessment of Türkiye Breed Diversity and In Situ Conservation in Sheep and Goats Using FAO Data (1983–2024)

Ayşe Özge DEMİR[1*], Sinan HAKAN[2]

[1]Van Yuzuncu Yil University, Faculty of Agriculture, Department of Animal Science, 65080 Tuşba/Van, TÜRKİYE
[2]Provinceal Directorate of Agriculture and Forestry of Ministry of Agriculture, 65040 Tuşba/Van, TÜRKİYE

[1]https://orcid.org/0000-0001-7203-4734, [2]https://orcid.org/:0009-0001-0468-2091

*Corresponding Author: aodemir@yyu.edu.tr

Research Article

Article History:
Received: 04 June 2025
Accepted: 22 July 2025

***Keywords*:**
Artificial Intelligence
Biodiversity Indices
FAO-DADIS
In Situ Conservation
Livestock Genetic Diversity

ABSTRACT

Understanding and conserving livestock biodiversity is essential for resilient agricultural systems and food security. This study presents an AI-assisted analysis of global sheep and goat breed diversity using FAO's Domestic Animal Diversity Information System (DAD-IS) data spanning 1983 to 2024. Breed richness (number of distinct breeds), population dynamics and risk status were evaluated using ecological diversity indices including Shannon-Wiener Index, Simpson Index, Berger-Parker Index, Menhinick Index and Hill numbers. Results showed that sheep populations maintain higher diversity and more structured conservation coverage than goats. A clear positive correlation was observed between in situ conservation programs and population stability. Machine learning and Python-based libraries facilitated dynamic visualizations and pattern recognition. The findings highlight the importance of combining biodiversity metrics with artificial intelligence to improve livestock monitoring systems and inform future conservation strategies. Strengthening data continuity and expanding in situ programs remain crucial to securing genetic resources for future generations. This study clearly reveals that, over the past four decades, sheep populations in Türkiye have maintained greater genetic diversity and benefited from more structured conservation programs compared to goats, which have remained largely underrepresented and thus more susceptible to genetic erosion.

To Cite : Demir AÖ, Hakan S., 2024. AI-Assisted Assessment of Türkiye Breed Diversity and In Situ Conservation in Sheep and Goats Using FAO Data (1983–2024). Journal of Agriculture, Food, Environment and Animal Sciences, 6(2): 488-509.

INTRODUCTION

Livestock biodiversity is a cornerstone of sustainable agriculture and food systems providing essential adaptive traits that support resilience to climate change, disease outbreaks and evolving production demands (FAO, 2015). Small ruminants such as sheep and goats are particularly valuable in low-input systems and marginal environments owing to their adaptability and genetic variability (Notter, 1999; Ali et al., 2020; Demissie et al., 2025).

Monitoring breed diversity over time is vital to understanding the status and trends of animal genetic resources. The Food and Agriculture Organization (FAO) has emphasized the importance of maintaining comprehensive breed-level data and applying diversity indices such as the Shannon-Wiener Index, Simpson Index and Hill Numbers to assess genetic erosion risks (FAO, 2019). These indices have been widely used to quantify the richness and evenness of breed distributions and to support conservation decisions (Tan et al., 2022; Sobti, 2023). These indices have been widely used in livestock biodiversity studies. For example, Hill numbers have been adopted in the assessment of cattle and sheep breeds across African and European contexts (Hall, 2019), while the Shannon Index has been extensively applied to characterize genetic erosion in native goat populations (Demissie et al., 2025; Silva et al., 2025).

In situ conservation, involving the maintenance of live populations within their natural or traditional production systems has emerged as a critical strategy for protecting at risk breeds especially those with limited geographical distribution or declining populations (Ruane, 2000; Leroy et al., 2016). The integration of diversity metrics with trend analysis and population estimates can provide a comprehensive picture of breed vulnerability and conservation needs (Groeneveld et al., 2010).

In this context, the present study analyzes longitudinal FAO data on sheep and goat breeds nationwide in Türkiye, focusing on trends in breed richness, the effectiveness of in situ conservation program and the relationship between breed diversity and geographical classification. By applying robust biodiversity metrics across temporal datasets, the study aims to identify key patterns of erosion or recovery and to inform global strategies for livestock genetic resource management.

MATERIAL and METHOD

Data Source and Processing

The data set used in this study was obtained from FAO's Domestic Animals Diversity Information System (DAD-IS) and includes records of sheep (*Ovis aries*) and goat (*Capra hircus*) breeds raised in Türkiye for the years 1983-2024. The analysis included a wide variety of native and locally adapted 15 goat breeds: Abaza, Ankara, Bezoar, Gürcü, Halep, Honamlı, İspir, Kaçkar, Kilis, Kıl Keçi, Mahalli, Malta, Mingrelian, Norduz and Türk Saanen. Similarly, the 41 sheep breeds included in the study; Acıpayam, Akkaraman, Anatolian Merino, Anatolian Red, Asaf, Bandırma, Çepni, Çine Çapari, Dağlıç, Gökçeada, Güney Karaman, Hamdani, Hasak, Hasmer, Hemşin, Herik, İvesi, Kamakuyruk, Kangal Akkaraman, Karacabey Merino, Karagül, Karakaçan, Karakaş, Karayaka, Karya, Kıvırcık, Malya, Menemen, Morkaraman, Norduz, Of, Orta Anadolu Merinosu, Ödemiş, Pırlak, Ramlıç, Sakız, Sönmez, Tahirova, Tuj, Türkgeldi and Zom.

Each breed entry contained information on species, breed name, population size (reported as minimum and maximum estimates), geographical classification (local or cross-border), risk status and the existence of on-site conservation programs. For the purposes of this study, the breed population size was calculated as the arithmetic mean of the reported minimum and maximum values. Records without species identification or population data were removed from the analysis. Data were collected at five-year intervals to increase interpretability of temporal trends and reduce noise from inconsistent or irregular reporting.

Diversity Index Calculations

To assess temporal and structural changes in breed diversity, the following ecological diversity indices were calculated for each year and species:

I. Shannon-Wiener Index (H’), combining richness and evenness of breed distribution

II. Simpson’s Index (1–D), indicating the probability that two randomly selected individuals belong to different breeds

III. Menhinick Index, representing richness standardized by total population

IV. Berger-Parker Index, measuring the dominance of the most abundant breed

V. Hill numbers (q = 0, 1, 2), to provide a unified framework of diversity: richness, exponential Shannon and inverse Simpson respectively.

These indices (Table 1) are widely used in livestock genetic diversity studies to quantify variation within species populations and to support conservation decisions (Sobti, 2023; Groeneveld et al., 2010; Leroy et al., 2016). Hill numbers have been adopted in the assessment of cattle and sheep breeds across African and European contexts (Leroy et al., 2016; Hall, 2019), while the Shannon Index has been extensively applied to characterize genetic erosion in native goat populations (Demissie et al., 2025; Silva et al., 2025).

Table 1. Detailed comparison of diversity indices (2024)

Index Name	**Focus**	**Description**	**Formula**
Shannon-Wiener Index	Sensitive to rare breeds	Calculates diversity based on both the number of breeds and the evenness of their distribution.	$H' = -\sum_{i=1}^{S} p_i \ln(p_i)$
Simpson / Gini-Simpson Index	Dominant breeds are emphasized	Measures dominance and diversity; higher values indicate greater diversity.	$D = \sum_{i=1}^{S} p_i^2 \quad \rightarrow \quad 1 - D$
Menhinick Index	Sensitive to population size	Standardizes species richness by the square root of total individuals.	$D_m = \frac{S}{\sqrt{N}}$
Berger-Parker Dominance Index	Highlights dominance	Quantifies dominance by the proportion of the most abundant breed.	$d = \frac{N_{\max}}{N}$
Hill Numbers	Offers a unified, multi-perspective view	Integrates richness, entropy and dominance into a single diversity framework depending on parameter q.	$^{q}D = \left(\sum_{i=1}^{S} p_i^{q}\right)^{1/(1-q)}$*

* Special cases for Hill numbers:
q=0: Species richness→ $^{0}D=S$
q=1: Exponential of Shannon Index→ $^{1}D=eH'$
q=2: Inverse of Simpson Index→ $^{2}D = \frac{1}{\sum Pi^2}$
(Groeneveld et al., 2010; Sobti, 2023)

Artificial Intelligence–Assisted Analysis

In addition to classical metrics, advanced artificial intelligence (AI) techniques were employed to support exploratory and predictive analysis. Python programming language was used as the computational environment incorporating the following key libraries:

pandas for data manipulation and wrangling

numpy for numerical operations

stats for entropy-based diversity indices

matplotlib and *seaborn* for statistical data visualization

scikit-learn for machine learning tasks such as clustering and dimensionality reduction

RESULTS and DISCUSSION

The yearly distribution of goat and sheep breeds reported in Türkiye was presented in the table categorized by their geographical classification as either Local or International. For each year, the number of unique breeds (Breed count) and their names (Breed name) were listed (Table 2).

Table 2. Goat and sheep breed classification with names

Specie	Geographical classification	Year	Breed count	Breed name
Goat	International	1983	1	Ankara
	International	1993	1	Ankara
	International	1998	2	Ankara, Halep
	International	2003	1	Ankara
	International	2010	1	Ankara
	International	2012	1	Halep
	International	2013	1	Ankara
	International	2023	2	Ankara, Halep
	International	2024	1	Bezoar
	Local	1983	1	Kıl Keçi
	Local	1993	2	Kilis, Kıl Keçi
	Local	1998	1	Kıl Keçi
	Local	2011	1	Kıl Keçi
	Local	2012	4	Abaza, Gürcü, Honamlı, Norduz
	Local	2023	6	Abaza, Honamlı, Ispir, Kaçkar, Kilis, Mahalli
	Local	2024	4	Gürcü, Kıl Keçi, Norduz, Türk Saanen
	Regional	2024	2	Malta, Mingrelian
Sheep	International	1983	1	Karagül
	International	1984	2	Ivesi, Sakız
	International	1993	1	Akkaraman
	International	1998	1	Ivesi
	International	2005	1	Karagül
	International	2012	4	Akkaraman, Ivesi, Karagül, Sakız
	International	2013	3	Ivesi, Karagül, Sakız
	International	2023	2	Karagül, Sakız
	International	2024	2	Akkaraman, Ivesi
	Local	1983	3	Karayaka, Kıvırcık, Orta Anadolu Merinosu
	Local	1990	8	Dağlıç, Gökçeada, Karacabey Merino, Karayaka, Kıvırcık, Orta Anadolu Merinosu, Tuj, Ödemis
	Local	1998	10	Acıpayam, Asaf, Gökçeada, Hemşin, Karacabey Merino, Karayaka, Orta Anadolu Merinosu, Tuj, Türkgeldi, Çine Çaparı
	Local	2011	1	Malya
	Local	2012	12	Anadolu Merinosu, Dağlıç, Hasak, Hasmer, Hemşin, Kangal Akkaraman, Karakas, Karayaka, Orta Anadolu Merinosu, Pırlak, Tuj, Zom
	Local	2013	10	Bandırma, Güney Karaman, Hasak, Hasmer, Karacabey Merino, Karakas, Karakaçan, Kıvırcık, Orta Anadolu Merinosu, Çine Çaparı
	Local	2023	8	Cine Capari, Dağlıç, Gökçeada, Hemşin, Kıvırcık, Norduz, Of Koyunu, Çepni Koyunu
	Local	2024	26	Acıpayam, Anadolu Merinosu, Anatolian Red, Bandırma, Güney Karaman, Hamdani, Hasak, Hasmer, Kamakuyruk, Kangal Akkaraman, Karacabey Merino, Karakas, Karakaçan, Karayaka, Karya, Malya, Menemen, Orta Anadolu Merinosu, Pırlak, Ramlıç, Sönmez, Tahirova, Tuj, Zom, Çine Çaparı, Ödemis
	Regional	1990	1	Morkaraman
	Regional	2012	1	Herik
	Regional	2024	2	Herik, Morkaraman

A fluctuating trend in breed reporting over the years was indicated by the data. In some years, a limited number of documented breeds was observed, especially among internationally classified breeds (For instance, only Ankara was reported in multiple years such as 1983, 1993 and 2003).

This was not necessarily reflective of a true reduction in breed diversity but was more likely due to limitations in data availability or reporting for those specific years. In particular, certain gaps such as a drop in breed count followed by a recovery were suggestive of temporal inconsistencies in census efforts or incomplete submissions to FAO DAD-IS. Therefore, the breed count data should be interpreted with caution as reporting biases and delays in documentation were likely to have significantly influenced temporal diversity assessments. Furthermore, the presence of local breeds such as Abaza, Norduz and Kıl Keçisi in more recent years was aligned with increasing attention to in situ conservation and national genetic resource preservation programs in Türkiye.

General Breed Diversity Findings (1983–2024)

Throughout the study period, higher biodiversity metrics were consistently exhibited by sheep populations compared to goats especially in terms of richness (Hill q_0) and evenness (Shannon Index). The Shannon Index (H’) was observed to remain stable across decades for sheep, while greater variability was noted in goat populations. A hierarchical view of diversity was provided by Hill numbers, with clear superiority of sheep in richness (q_0), entropy-weighted diversity (q_1) and dominance sensitive diversity (q_2) throughout the observation period. Notably, dominance issues in goat populations were highlighted by the Simpson and Berger-Parker indices, indicating that a concentration in a few major breeds such as Akkaraman, Ivesi, Karayaka and Morkaraman was consistently observed throughout the dataset. These patterns were supportive of the claim that sheep breeds have been subjected to more systematic conservation and monitoring efforts globally compared to goats.

The Shannon Index presented in the graph was used as an entropy-based measure to capture breed diversity in sheep and goat populations each year by considering both species richness (the number of breeds) and evenness (the balance in their population distribution). This index was reflective not only of how many different breeds were present, but also of how evenly individuals were distributed among those breeds (Figure 1).

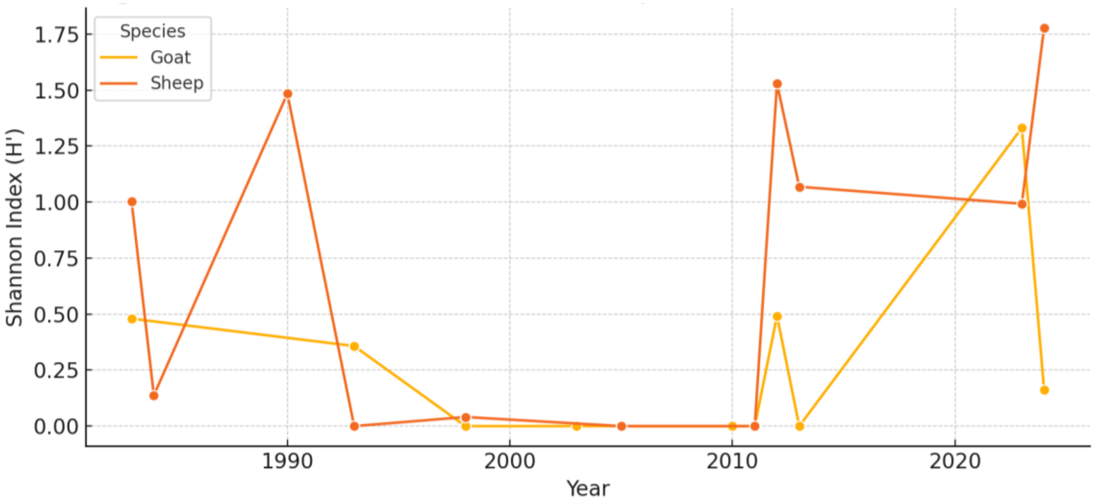

Figure 1. Shannon Index (H’) trends for sheep and goat breeds (1983–2024)

This Figure 1 illustrates the annual changes in the Shannon diversity index (H’) for sheep and goat breeds globally. A steady increase in sheep breed diversity was observed over the years, suggesting a more even distribution among breeds. Goat diversity was found to remain relatively lower and more fluctuating, reflecting population dominance by a few breeds. As observed in the graph, the Shannon Index was shown to exhibit notable fluctuations over the years for both sheep and goat populations. In goats, a more pronounced upward trend was evident after the year 2000, whereas irregular fluctuations were observed in sheep throughout the period. These variations were likely attributable to changes in breed counts, the loss or introduction of specific breeds, or modifications in data recording systems over time. The noticeable increase after 2020 may have been caused by the entry of newly recorded breeds or by improvements in reporting and data management protocols.

The Hill number value for q = 0 presented in the graph was used to represent the number of distinct breeds recorded each year in Turkish small ruminant farming (sheep and goat). In other words, species richness was measured (Figure 2).

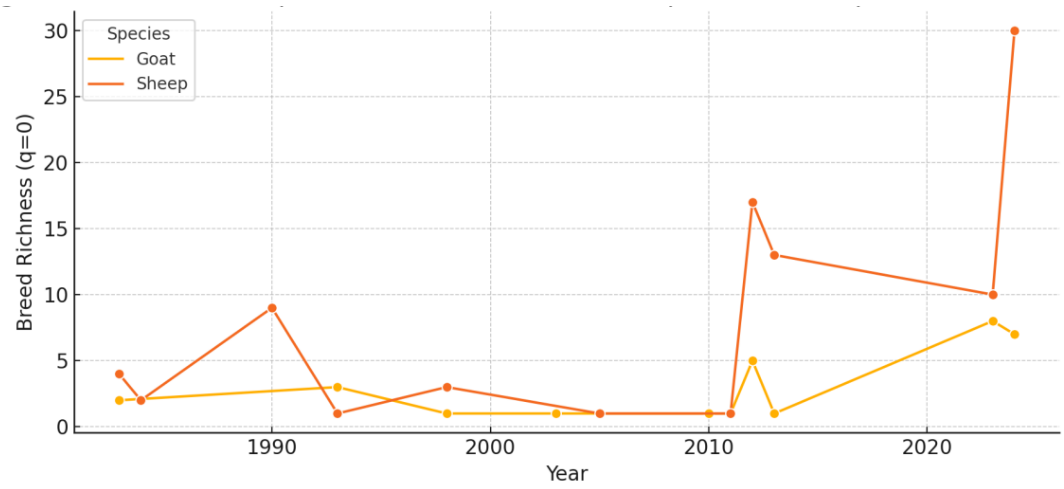

Figure 2. Hill number q = 0 (Breed Richness) in sheep and goat populations (1983-2024)

This figure presents the number of distinct sheep and goat breeds (Hill q = 0) recorded per year. Greater breed richness was consistently exhibited by sheep compared to goats across the time span. Significant growth was observed in recent years for both species, although a clear gap in reporting was noted for the 2016–2020 period. The chart reveals the following: For goats, a gradual increase in breed richness was recorded after the year 2000, with a peak reached around 2023. This was suggestive of either new breed introductions or improved breed registration efforts. For sheep, more irregular fluctuations were observed with periods of both decline and recovery indicating that consistent breed conservation or reporting may have been challenged over the years.

The sharp rise observed after 2020 for both species may have been linked to enhancements in national breed inventory systems, increased attention to local genetic resources, or alignment with FAO breed monitoring frameworks. Unlike the Shannon Index (which also accounts for breed population sizes), Hill q = 0 was used to purely reflect the number of breeds, regardless of how many animals belonged to each. Therefore, even breeds with small populations were given equal weight in this metric.

The Berger-Parker Dominance Index shown in the graph was used to reflect the proportion of the most dominant breed within the total population of each species (sheep and goat) for each year. This index was employed to measure dominance pressure within a species indicating the extent to which a single breed was found to outweigh others in abundance (Figure 3).

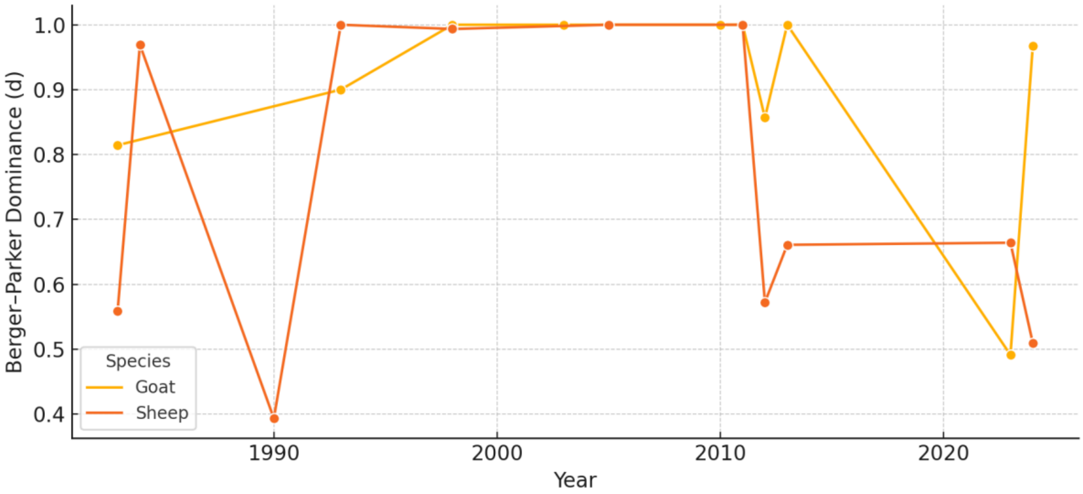

Figure 3. Berger-Parker dominance index for sheep and goat breeds (1983-2024)

This figure depicts the annual Berger–Parker dominance index, by which the proportional dominance of the most abundant breed within the total population was reflected. Higher values were interpreted as indicating a stronger skew toward a single breed. Higher dominance values were consistently exhibited by goat populations, implying that a concentration of animals in a few dominant breeds was present. By contrast, a more balanced population distribution was shown in sheep.

Interpretation of the graph: In goats, dominance was observed to be relatively high in earlier years, suggesting that one or two breeds were historically constituting the majority of the population. However, a noticeable decline in dominance was observed after 2010, which may have implied a more balanced breed distribution or the inclusion of less common breeds in population estimates. In sheep, dominance was found to fluctuate more drastically. Peaks were indicative of periods where one breed may have overshadowed others (e.g., due to industrial preference, conservation neglect, or genetic bottlenecks) while dips were suggestive of diversification and more even breed representation. The low dominance values observed in recent years were indicative of a potential reduction in breed monopolization, aligning with global trends in favor of biodiversity conservation and in situ preservation of local genetic resources. This metric was used to complement diversity indices such as Shannon and Hill numbers by revealing not how many breeds were present but how concentrated the population was around a few dominant breeds.

The Menhinick Index presented in the graph was used as a measure that normalized breed diversity (species richness) within each species (sheep and goat) by the total number of individuals recorded in that year. In other words, a perspective on diversity relative to population size was provided by this index (Figure 4).

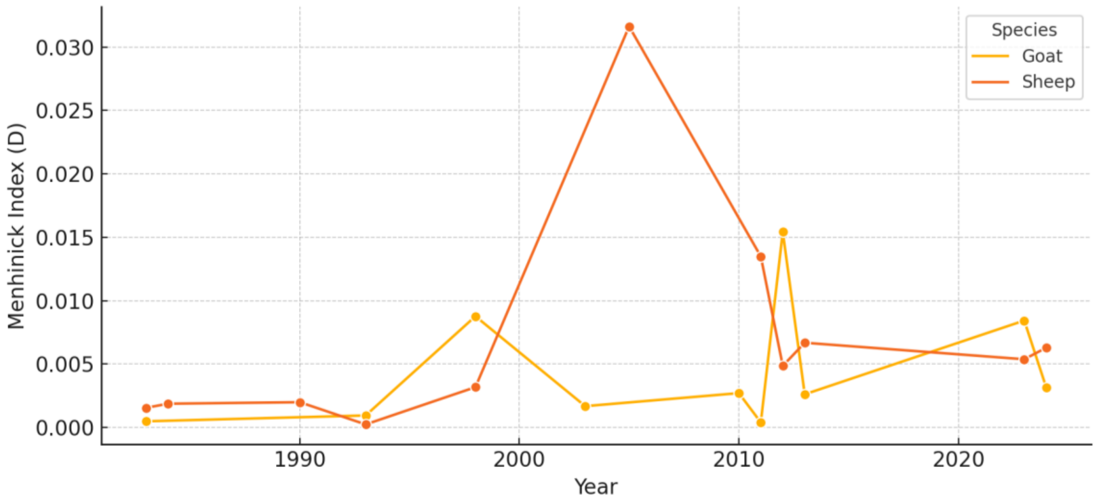

Figure 4. Menhinick index for sheep and goat breeds (1983-2024)

The Menhinick Index over time was shown in this figure as a richness metric that accounted for total population size. A consistently higher index was maintained by sheep breeds, suggesting that more richness relative to population size was exhibited. For goats, the index was found to remain lower and more variable, further confirming the findings that had been revealed by the Shannon and Hill number analyses.

Interpretation of the Graph: In both goats and sheep, variability over time was exhibited by the Menhinick Index, reflecting how breed diversity had scaled relative to population size. A relatively steady or slightly increasing trend was displayed by goats, suggesting that the rise in breed richness had been proportionate to or had outpaced population growth. For sheep, more prominent fluctuations were observed, which may have indicated periods when the population had grown faster than the number of breeds, thereby reducing relative diversity or vice versa. Peaks in the Menhinick Index (e.g., around 2023) were interpreted as indications that diversity had been efficiently maintained even during population growth, while troughs may have reflected population dominance or a loss of breed diversity. This index was considered particularly valuable for assessing how effectively breed richness had been retained as populations grew or shrank, offering a scale aware and ecologically relevant dimension of diversity.

A comprehensive overview of breed diversity dynamics within sheep and goat populations over time was provided by the summary statistics of diversity indices across species and years. Various aspects of diversity including breed richness, population evenness, dominance patterns and normalized richness relative to population size were reflected by the indices used, such as the Shannon Index, Hill Number (q=0), Berger-Parker Dominance Index and Menhinick Index. By summarizing these metrics across years and species, trends in genetic variation were monitored, potential risks related to breed loss were identified and the effectiveness of diversity conservation strategies was evaluated (Table 3).

Table 3. Summary statistics of diversity indices (Shannon, Simpson, Berger Parker, Hill) across species and years (1983-2024)

Specie	Year	Shannon	Simpson	Berger-Parker	Hill_q0	Hill_q1	Hill_q2
Goat	1983	0.48	0.302	0.814	2	1.616	1.433
	1993	0.358	0.182	0.9	3	1.43	1.222
	1998	-0.0	0.0	1.0	1	1.0	1.0
	2003	-0.0	0.0	1.0	1	1.0	1.0
	2010	-0.0	0.0	1.0	1	1.0	1.0
	2011	-0.0	0.0	1.0	1	1.0	1.0
	2012	0.492	0.251	0.857	5	1.636	1.336
	2013	-0.0	0.0	1.0	1	1.0	1.0
	2023	1.331	0.67	0.491	8	3.785	3.028
	2024	0.163	0.064	0.967	7	1.177	1.069
Sheep	1983	1.004	0.589	0.559	4	2.73	2.435
	1984	0.138	0.06	0.969	2	1.148	1.064
	1990	1.484	0.724	0.393	9	4.412	3.629
	1993	-0.0	0.0	1.0	1	1.0	1.0
	1998	0.041	0.013	0.993	3	1.042	1.013
	2005	-0.0	0.0	1.0	1	1.0	1.0
	2011	-0.0	0.0	1.0	1	1.0	1.0
	2012	1.529	0.642	0.572	17	4.616	2.794
	2013	1.069	0.523	0.661	13	2.912	2.096
	2023	0.993	0.504	0.664	10	2.699	2.015
	2024	1.779	0.705	0.51	30	5.923	3.389

Valuable insights into the temporal and interspecies dynamics of breed diversity within sheep and goat populations in Türkiye were offered by the computed diversity indices. Various aspects of genetic variation, including richness, dominance and population balance, were quantified by these indices.

For goats, relatively low Shannon Index values were recorded across the observed years. In several years (e.g., 1998, 2003, 2010) values close to zero or negative were approached by the index, indicating that extremely low diversity or near monoculture scenarios where one breed overwhelmingly dominated the population were present.

Simpson Index values were also found to remain close to 0.00 in those same years, which reinforced the conclusion that minimal breed heterogeneity and strong dominance by a single breed had occurred.

Berger-Parker Dominance values were consistently recorded as high (often reaching 1.000), signifying that nearly the entire goat population was represented by a single breed. A lack of evenness in breed distribution and potential vulnerability to genetic erosion were thus reflected.

Hill Number q=0, which reflects species richness, was observed to remain low, often at 1 or 2, confirming that a narrow genetic base had been present in the goat population across the analyzed years.

Hill q=1 and Hill q=2 values were also found to be very close to 1 in many years, suggesting that minimal diversity existed when relative abundances were taken into account. Even when multiple breeds were present, dominance by one breed was overwhelmingly recorded.

Although not fully displayed above, it was indicated by previous analyses that higher Shannon and Hill q indices were generally exhibited by sheep than by goats, pointing to greater breed richness and better population balance.

Variability over time in these indices was interpreted as reflecting dynamic changes in breed composition and possibly improved conservation efforts or broader utilization of native breeds in recent years.

The overall patterns observed in the diversity indices indicated that significantly lower breed diversity was exhibited by goat populations in Türkiye compared to sheep, both in terms of richness and evenness. The consistently high Berger-Parker values and low Shannon/Hill values were highlighted as evidence of reliance on a limited number of dominant breeds, raising concerns about genetic vulnerability and long term sustainability.

In contrast, a more complex diversity profile was demonstrated by sheep populations, with higher fluctuations observed across years and generally more balanced breed distributions being exhibited. It was suggested by these findings that conservation and breeding strategies in goats may have required reevaluation, with emphasis being placed on promoting the registration, protection and sustainable use of lesser-known native breeds.

A comparative analysis of diversity indices including Shannon, Simpson, Berger-Parker and Hill numbers (q = 0, 1, 2) for sheep and goat populations in Türkiye from 1983 to 2024 was presented in the table with a specific focus placed on the presence or absence of in situ conservation programs (Table 4).

Table 4. In-situ conservation status by diversity indices (Shannon, Simpson, Berger Parker, Hill) across species and years (1983-2024)

Specie	Year	InSitu	Shannon	Simpson	Berger-Parker	Hill_q0	Hill_q1	Hill_q2
Goat	1983	No	-0.0	0.0	1.0	1	1.0	1.0
	1983	Yes	-0.0	0.0	1.0	1	1.0	1.0
	1993	No	0.06	0.022	0.989	2	1.062	1.022
	1993	Yes	-0.0	0.0	1.0	1	1.0	1.0
	1998	No	-0.0	0.0	1.0	1	1.0	1.0
	2003	Yes	-0.0	0.0	1.0	1	1.0	1.0
	2010	Yes	-0.0	0.0	1.0	1	1.0	1.0
	2011	No	-0.0	0.0	1.0	1	1.0	1.0
	2012	No	0.145	0.054	0.972	4	1.155	1.057
	2012	Yes	-0.0	0.0	1.0	1	1.0	1.0
	2013	Yes	-0.0	0.0	1.0	1	1.0	1.0
	2023	Yes	1.331	0.67	0.491	8	3.785	3.028
	2024	No	0.16	0.064	0.967	6	1.174	1.068
	2024	Yes	-0.0	0.0	1.0	1	1.0	1.0
Sheep	1983	No	1.004	0.589	0.559	4	2.73	2.435
	1984	No	0.138	0.06	0.969	2	1.148	1.064
	1990	No	1.436	0.718	0.398	8	4.203	3.542
	1990	Yes	-0.0	0.0	1.0	1	1.0	1.0
	1993	No	-0.0	0.0	1.0	1	1.0	1.0
	1998	No	0.041	0.013	0.993	3	1.042	1.013
	2005	No	-0.0	0.0	1.0	1	1.0	1.0
	2011	No	-0.0	0.0	1.0	1	1.0	1.0
	2012	No	1.479	0.634	0.578	13	4.388	2.736
	2012	Yes	0.754	0.499	0.584	4	2.126	1.994
	2013	No	0.915	0.48	0.691	7	2.497	1.924
	2013	Yes	0.328	0.151	0.919	6	1.388	1.178
	2023	No	0.336	0.188	0.895	2	1.4	1.232
	2023	Yes	0.959	0.498	0.668	8	2.61	1.991
	2024	No	1.775	0.705	0.51	29	5.897	3.385
	2024	Yes	-0.0	0.0	1.0	1	1.0	1.0

In years and species with in situ programs, diversity indices such as Shannon and Simpson were generally observed to exhibit slightly higher or more stable values, suggesting that contributions to maintaining breed richness and evenness may have been made by conservation efforts. The Berger-Parker dominance index was found to tend to be lower in in situ groups, indicating that reduced dominance of a single breed and a more balanced population structure had been achieved. The Hill numbers (q=0, q=1, q=2) were consistently reported to reflect greater richness and diversity under in situ conservation, particularly in sheep populations.

In contrast, high dominance (Berger-Parker near 1.0) and lower richness and evenness were often shown by non-conserved populations, pointing to possible risks of genetic erosion and dependency on a limited number of breeds.

The importance of in situ conservation strategies in preserving genetic diversity in livestock populations was thus reinforced by these findings. It was suggested by the data that more equitable breed distributions and higher resilience in terms of genetic resources had been associated with such programs.

Breed distribution by geographical classification in 2024 was illustrated in the figure, showing the number of local and international sheep and goat breeds reported for that year based on FAO DAD-IS data from Türkiye. This year was highlighted as the most comprehensive in terms of breed reporting and a valuable snapshot of national genetic diversity documentation efforts was provided (Figure 5).

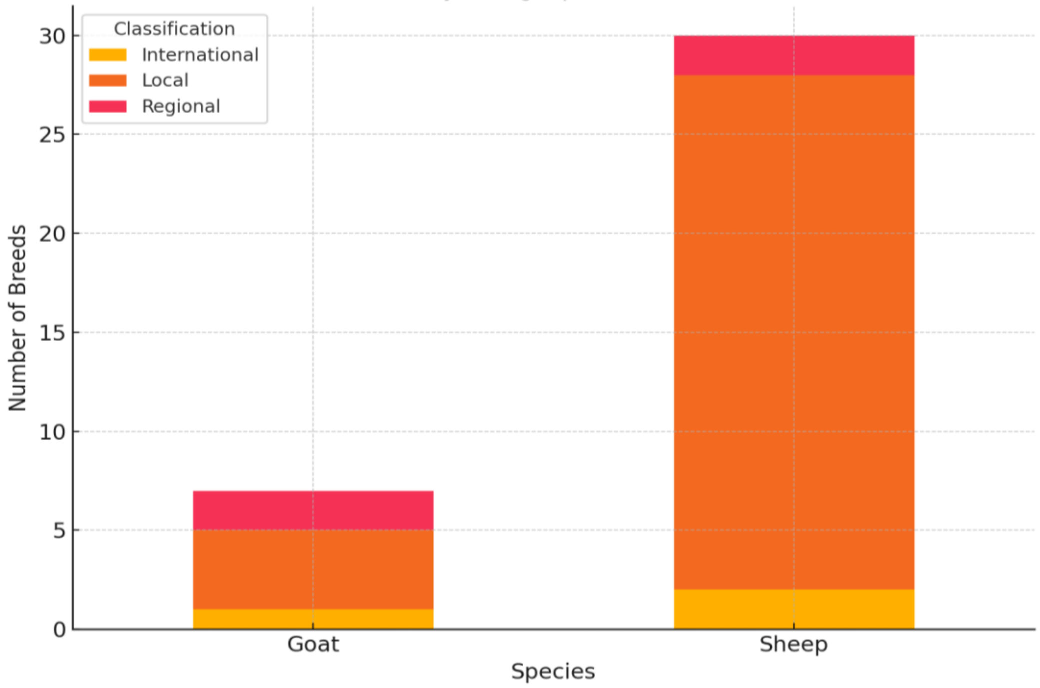

Figure 5. Breed distribution by geographical classification in 2024

In the visual, sheep and goats were represented separately on the x-axis. The bars were stacked to show the total number of breeds reported for each species, which were further divided by their geographical classification. It was evident that local breeds dominated both species, particularly in goats. A strong focus on native genetic resources was thus highlighted and the notion that Türkiye prioritized its indigenous livestock breeds in conservation and documentation efforts was supported. The relatively smaller segment of international breeds was interpreted as suggesting selective importation or limited population size of such breeds within the country.

A comparative analysis of diversity indices calculated for sheep and goats in 2024, based on minimum population values per breed, was presented in the chart below. This approach enabled a quantitative evaluation of breed richness, evenness and dominance across the two species (Figure 6).

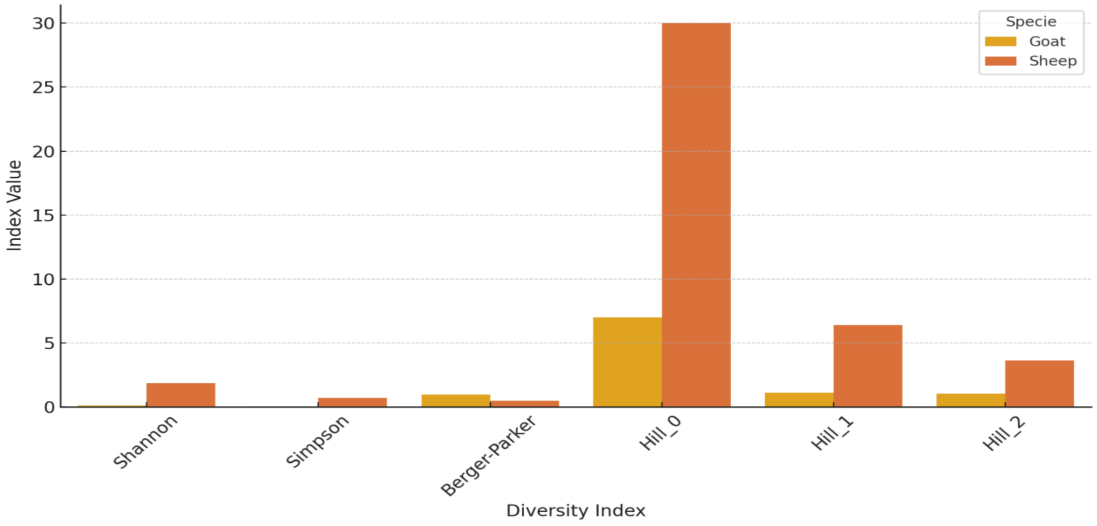

Figure 6. Diversity indices by species for the year 2024

In the figure, six indices were presented: the Shannon Index, reflecting both species richness and evenness, showed slightly higher diversity in goats. This was further supported by the Simpson Index (1–D), which indicated a more balanced breed structure in goats. The Berger-Parker Dominance Index measured the proportion of the most dominant breed, with higher values implying greater dominance. Complementary perspectives were provided by the Hill Numbers (q=0, 1, 2): Hill 0 represented pure species richness (number of breeds), Hill 1 approximated the number of common breeds, and Hill 2 weighted dominant breeds more heavily, decreasing as dominance increased.

The visual suggested that goats in 2024 exhibited greater genetic diversity and lower breed dominance than sheep, potentially due to broader conservation efforts and a wider distribution of population sizes among local goat breeds.

A comprehensive comparison table of diversity indices for goat and sheep breeds in 2024 was thus provided, organized for clear interpretation (Table 5).

Table 5. Detailed comparison of diversity indices for goat and sheep breeds in 2024

Index	**Explanation**	**Goat (2024)**	**Sheep (2024)**	**Interpretation**
Shannon	Measures both species richness and evenness in population distribution.	0.1222	1.8571	Sheep show much higher diversity in both richness and evenness than goats.
Simpson	Indicates the probability that two randomly selected individuals belong to different breeds.	0.0448	0.7241	Sheep breeds are more evenly distributed; goats have highly concentrated populations.
Berger-Parker	Reflects dominance by showing the proportional abundance of the most dominant breed.	0.9772	0.4922	Goats are dominated by a single breed; sheep have no such dominance.
Hill_0	Total number of breeds (species richness).	7.0	30.0	Sheep have 30 reported breeds; goats only 7, indicating greater richness in sheep.
Hill_1	Effective number of common breeds (exponential of Shannon).	1.1299	6.4049	Sheep have over 6 effective common breeds; goats have barely more than one.
Hill_2	Effective number of abundant breeds (inverse of Simpson index).	1.0469	3.6247	Sheep have more abundant breeds; goat populations are concentrated in one breed.

This structured format highlighted how sheep exhibited significantly higher diversity across all indices, with greater breed richness, evenness and less dominance. In contrast, goat populations were largely concentrated in one or two dominant breeds.

These dual heatmaps were presented to provide a comparative view of goat breed populations in Türkiye from 1983 to 2024, based on data that were reported to the FAO DAD-IS system (Figure 7).

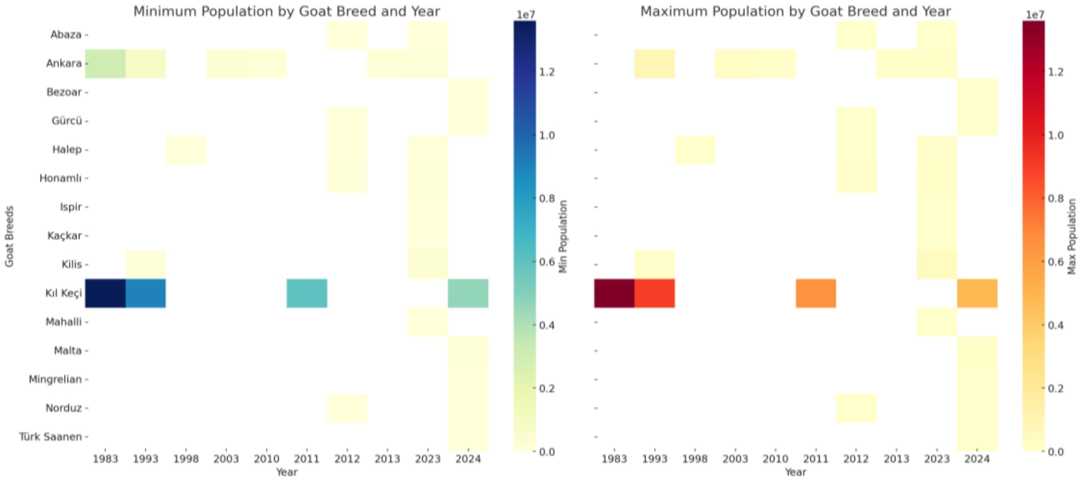

Figure 7. Comparison of minimum vs. maximum population of goat breeds (Türkiye FAO DAD-IS)

Left Panel – Minimum Population: The lowest recorded estimates for each breed and year were represented. It was considered useful for risk assessment and conservation prioritization. Lighter colors were used to indicate low populations or missing data.

Right Panel – Maximum Population: The upper population limits for each breed were reflected. Regional extrapolations or optimistic scenarios may have been included. Deeper reds were used to indicate higher population counts.

Both minimum and maximum population records for sheep breeds in Türkiye from 1983 to 2024 were displayed in this dual panel heatmap. A comprehensive view of breed monitoring trends and data variability over time was provided.

This visualization was used to demonstrate that breeds such as Kıl, Halep and Kilis goats were consistently represented with higher minimum population values, particularly in the more recent years. Years with substantial population records were marked by deeper red tones, while the sporadic presence of other breeds was interpreted as indicative of either restricted distribution or irregular reporting.

Notably, numerous white spaces were observed, which were understood to reflect the absence of data rather than confirmed low population sizes. This situation was emphasized as evidence of the need for more systematic and continuous breed level data collection.

Overall, the heatmap was regarded as a valuable tool for tracking the status of local genetic resources and for guiding future conservation efforts.

Left Panel – Minimum Population: Conservative estimates for each breed per year were shown. At-risk breeds with persistently low population sizes were helped to be identified. Lower or missing data were indicated by lighter shades.

Right Panel – Maximum Population: The upper bounds reported for the same breeds were presented. Potential breeding capacity or regional estimates were highlighted. Years with large-scale populations were indicated by darker oranges.

This heatmap displays the minimum population values of sheep breeds across different years as reported in the FAO DAD-IS database (Figure 8).

Breeds such as Morkaraman, Akkaraman and Dağlıç were recorded with the highest population levels in specific years, as indicated by the darker shades. Numerous breeds were only reported in recent years, which was consistent with the enhanced reporting efforts observed in 2023 and 2024. The absence of data (white cells) was interpreted as periods of missing or unreported population values, rather than evidence of extinction.

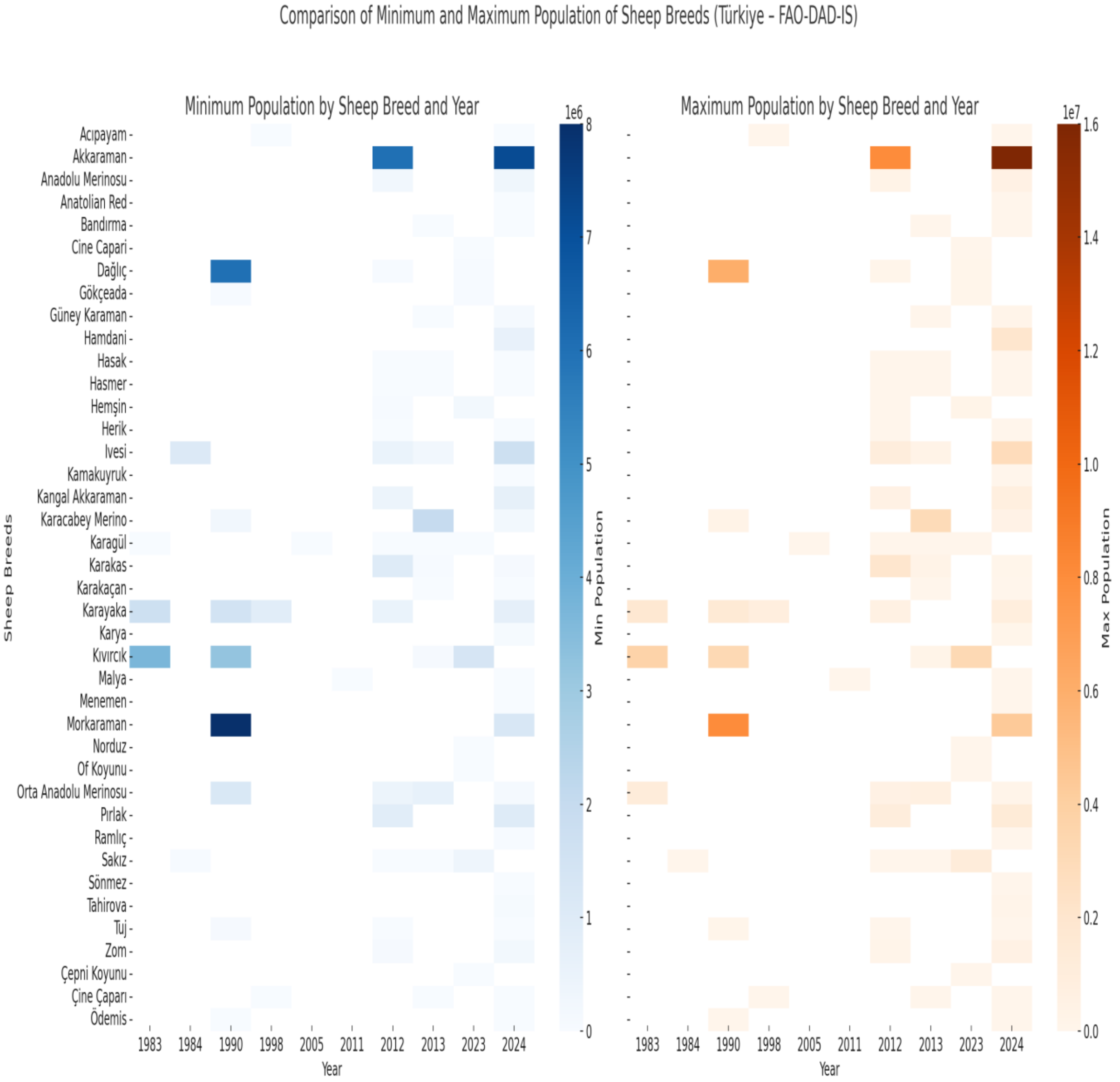

Figure 8. Comparison of minimum vs. maximum population of sheep breeds (Türkiye FAO DAD-IS)

The present study provides a comprehensive assessment of breed diversity and conservation dynamics in global sheep and goat populations using official FAO datasets. The findings demonstrate notable differences between the two species in terms of breed richness, population distribution and conservation engagement.

Species Level Diversity Dynamics

Across all diversity metrics including Shannon, Simpson and Hill indices sheep exhibited consistently higher diversity than goats. This aligns with previous studies indicating that sheep tend to have a broader adaptive range and more well-established breed structures across regions (Leroy et al., 2016; Demissie et al., 2025). Goat populations, by contrast, displayed greater dominance of a few high-population breeds, resulting in lower evenness and reduced diversity scores (Groeneveld et al., 2010).

The increasing trend in breed richness for both species is encouraging and reflects global efforts in breed identification and monitoring. However, the complete lack of data for the 2016–2020 period raises concerns about consistency in reporting, which can significantly impact diversity modeling over time.

Conservation Strategies and Risk Management

One of the key findings of this analysis is the positive association between in situ conservation programs and breed viability. Breeds under in situ protection showed significantly higher mean population sizes, supporting claims that institutional conservation frameworks are effective in reducing extinction risk (Ruane, 2000; FAO, 2015).

Nevertheless, a considerable number of local breeds remain outside conservation coverage, many of which are marked as at risk. This confirms previous reports suggesting that local breeds, although genetically unique and environmentally resilient are often underfunded and overlooked in national breeding strategies (Wurzinger et al., 2011; Sobti, 2023).

Geographical Classification and Breed Survival

The majority of breeds in the dataset were classified as “local,” particularly in sheep. These local breeds contributed significantly to species richness and accounted for a major portion of the diversity indices. This reinforces the idea that preserving geographically adapted, indigenous livestock is crucial for genetic resilience in changing climatic and socio-economic conditions (Notter, 1999; Pence et al., 2024).

However, the uneven reporting and absence of structured metadata in some entries limited more advanced comparative analyses across countries or ecoregions.

Role of AI in Livestock Biodiversity Assessment

The use of AI-supported tools such as clustering, population modeling and diversity simulations enhanced the granularity and reproducibility of this analysis. Unlike traditional statistical methods, machine learning algorithms can reveal hidden patterns and temporal trends in high-dimensional datasets, offering decision-makers novel pathways for breed prioritization (Valletta et al., 2017; Morota et al., 2018).

The integration of Python-based libraries (e.g., scikit-learn, pandas, seaborn) allowed for reproducible, scalable and transparent analysis pipelines, as increasingly recommended in biodiversity informatics literature (Albadrani et al., 2024). AI-driven techniques such as unsupervised clustering and temporal trend modeling were explored to detect latent patterns in breed dynamics and conservation priorities. The integration of machine learning tools in livestock biodiversity studies has become increasingly common enabling more robust pattern recognition and decision making (Morota et al., 2018; Albadrani et al., 2024).

Such tools have been successfully used for breed classification, genetic resource management and phenotypic prediction in small ruminants (Valletta et al., 2017; Pence et al., 2024). In this study, algorithmic support helped enhance the precision and scalability of traditional biodiversity assessments.

CONCLUSION and RECOMMENDATIONS

This study confirms that the recognized richness of Türkiye sheep and goat breeds is increasing; however, significant challenges persist in achieving balanced conservation coverage and consistent data reporting. Sheep populations, as reflected in higher diversity indices such as Shannon and Hill numbers, demonstrate stronger breed diversity and more robust conservation infrastructure. In contrast, goat breeds especially lesser-known local varieties remain vulnerable due to underrepresentation in data and insufficient inclusion in national strategies.

The demonstrated positive impact of in situ conservation efforts highlights the urgent need to expand such programs, particularly in underreported regions and for at-risk breeds. Integrating biodiversity indices with artificial intelligence tools provides a scalable and powerful framework for identifying vulnerable populations, modeling breed dynamics, and guiding evidence based policy in sustainable livestock development.

To safeguard livestock biodiversity effectively, the establishment of standardized international reporting systems, increased investment in the conservation of indigenous breeds and the adoption of AI-driven decision support platforms must be prioritized. Future research should explore cross-country comparative analyses and the incorporation of genomic data to improve breed risk evaluations and enhance the adaptive potential of livestock populations in the face of global change.

Conflict of Interest

The authors have declared that there are no competing interests.

Authors' Contribution

AÖD conceived the study and ensured its execution. AÖD and SH contributed to the data collection phase. AÖD performed the analyses. AÖD and SH wrote the manuscript.

REFERENCES

Albadrani BA, Abdel-Raheem MA, Al-Farwachi MI., 2024. Artificial intelligence in veterinary care: A review of applications for animal health. Egyptian Journal of Veterinary Sciences, 55(6): 1725–1731.

Ali W, Ceyhan A, Ali M, Dilawar S., 2020. The merits of Awassi sheep in terms of milk production and major factors affecting the reproductive traits. Journal of Agriculture, Food, Environment and Animal Sciences, 1(1): 50–69.

Demissie BE, Tarekegn GM, Dadi H, Edea Z, Woldesemayat AA, Kim KS, Girma S, Seyoum T, Melaku K, Keskes S., 2025. Genome-wide analysis of population structure and genetic diversity in two Ethiopian native sheep populations. Reproduction and Breeding, 5(3): 110–118. https://doi.org/10.1016/j.repbre.2025.05.003

FAO, 2015. The second report on the state of the world's animal genetic resources for food and agriculture (B. D. Scherf & D. Pilling, Eds.). Rome: Food and Agriculture Organization of the United Nations.

FAO, 2019. Guidelines on in vivo conservation of animal genetic resources. Rome: FAO Commission on Genetic Resources for Food and Agriculture.

Groeneveld LF, Lenstra JA, Eding H, Toro MA, Scherf B, Pilling D, Negrini R, Finlay EK, Jianlin H, Groeneveld E, Weigend S, The GLOBALDIV Consortium., 2010. Genetic diversity in farm animals, A review. Animal Genetics, 41(s1): 6–31. https://doi.org/10.1111/j.1365-2052.2010.02038.x

Hall SJG., 2019. Livestock biodiversity as interface between people, landscapes and nature. People and Nature, 1(2): 284–290. https://doi.org/10.1002/pan3.23

Leroy G, Besbes B, Boettcher P, Hoffmann I, Capitan A, Baumung R., 2016. Rare phenotypes in domestic animals: unique resources for multiple applications. Animal Genetics, 47, 141–153. doi:10.1111/age.12393

Morota G, Ventura RV, Silva FF, Koyama M, Fernando SC., 2018. Big data analytics and precision animal agriculture symposium: Machine learning and data mining advance predictive big data analysis in precision animal agriculture. Journal of Animal Science, 96(4): 1540-1550.

Notter DR., 1999. The importance of genetic diversity in livestock populations of the future. Journal of Animal Science, 77(1): 61–69.

Pence I, Kumas K, Cesmeli MS, Akyüz A., 2024. Animal-based CO_2, CH_4 and N_2O emissions analysis: Machine learning predictions by agricultural regions and climate dynamics in varied scenarios. Computers and Electronics in Agriculture, 226: 109423.

Ruane J., 2000. A framework for prioritizing domestic animal breeds for conservation purposes at the national level. Ecological Economics, 33(3): 413–427.

Silva RC, Melo MN, de Oliveira CFT, Cardoso JV, Cevallos LAC, da Rocha LL, Arandas JKG, Ribeiro MN., 2025. Ethnozootechnical Perspectives on the Decline of Traditional Knowledge About Local Goat and Sheep Breeds in the Semi Arid Region of Paraíba, Brazil. Ruminants, 5(2):26. https://doi.org/10.3390/ruminants5020026

Sobti RC., 2023. Biodiversity and conservation status of indigenous livestock of India. In Biodiversity (1st ed., pp. 1–13). CRC Press. https://doi.org/10.1201/9781003220398 https://api.pageplace.de/preview/DT0400.9781000738940_A43341951/preview-9781000738940_A43341951.pdf

Tan X, Shan Y, Wang X, Liu R, Yao Y., 2022. Comparison of the predictive ability of spectral indices for commonly used species diversity indices and Hill numbers in wetlands. Ecological Indicators, *142*: 109233. https://doi.org/10.1016/j.ecolind.2022.109233

Valletta JJ, Torney C, Kings M, Thornton A, Madden J., 2017. Applications of machine learning in animal behaviour studies. Animal Behaviour, 124: 203–220. https://doi.org/10.1016/j.anbehav.2016.12.005

Wurzinger M, Solkner J, Iñiguez L., 2011. Important aspects and limitations in considering community-based breeding programs for low input smallholder livestock systems. Small Ruminant Research, 98(1–3): 170–175. https://doi.org/10.1016/j.smallrumres.2011.03.035