

Classification of donkey systems in Ethiopia

Abstract

Working equids play a critical role in transportation, agriculture and household resilience in low- and middle-income countries. Other animals that are kept for production purposes, such as cattle, are often grouped into broad production system classes, such as dairy or pastoral, for comparison between and better understanding of the needs and outputs of animals within specific sectors. Despite the importance of working equids for sustaining livelihoods there are no systematic classifications of these populations. The aim of this study was to classify working donkeys in Ethiopia using household-level questionnaire data which included donkey ownership, husbandry, use and local environment data, through multiple factor analysis and hierarchical cluster analysis. Household questionnaire data from 241 donkey-owning households in three districts of Ethiopia were used. Three distinct clusters of donkey ownership were identified: ‘Domestic-Pastoral’; ‘Domestic-Agricultural’ and ‘Commercial’. Donkey purpose, environmental (agro-ecological) factors, and husbandry practices had the largest influence on household clustering. Constraints associated with donkey ownership varied across clusters: households in the commercial system reported higher incidence of injuries and welfare concerns, in the pastoral system the main constraints were drought and feed shortage, and domestic-agricultural households reported infectious diseases as the main challenge. This new classification of donkey systems provides a framework for analyzing donkey health and welfare data, enabling more context-specific needs assessments and facilitating the design of targeted interventions to improve equid health and household livelihoods.

Key words: Classification; Donkey; Equine; Ethiopia; Production systems; Working animals

Introduction

Working equids contribute significantly to the national economy in Ethiopia and support the livelihoods of millions of households (Geiger et al., 2020; Metaferia et al., 2011; Stringer, 2014). In 2021 the growing equine population was 13.3 million and accounted for 10% of the total livestock biomass in the country (Asteraye et al., 2024). The income generated by working equids in central Ethiopia is comparable to that generated from livestock farming (Admassu and Shiferaw, 2011) and their value as draft animals is equivariant to 1% of the national GDP (Asteraye et al., 2024). The number of people and households owning equids in Ethiopia has steadily increased over the past two decades. Half of rural households in Ethiopia own working equids, predominantly donkeys (Asteraye et al., 2024). Working equids are especially important to vulnerable groups, such as landless communities and women. They provide a source of income and serve as draft animals in areas lacking agricultural mechanization (Admassu and Shiferaw, 2011; Stringer, 2014). Despite their importance across Ethiopia working equids and the domestic and agricultural systems they are kept in are poorly studied and receive limited policy attention.

The purpose, environment, enterprise patterns and intensity of livestock production vary greatly within and between countries. However, enough similarities appear across production systems which allow them to be categorized into broader systems - for example the pastoral or intensive dairy systems (Robinson et al., 2011). Livestock are often grouped this way so that resource allocation can be targeted (Li et al., 2024; Notenbaert et al., 2009; Steinfeld et al., 2006). Agricultural policies and investments in the livestock sector have more successful outcomes when they account for the multiple dimensions of livestock farming (FAO, 2018a, 2018b). In contrast, it has been suggested that low adoption of agricultural interventions could be attributed to use of

blanket recommendations that do not consider the diverse agro-ecological and socio-economic conditions of farming systems (Gizaw et al., 2017; Thornton et al., 2007). This has led to a growing interest in transitioning from broad, sector-level agricultural statistics to more specific, disaggregated data at locally relevant scales (FAO, 2018a). Systematic classification and characterization of production systems in agricultural research have enabled policy makers and stakeholders to develop targeted policy and development interventions that are specific and meet the needs of the people and animals they aim to serve (Gizaw et al., 2017; Steinfeld et al., 2006).

In Ethiopia cattle and small ruminants have previously been classified into; pastoral, agro-pastoral, mixed crop-livestock, peri-urban, and urban and different sub-systems exist within these broader classes (FAO, 2018b; Gizaw et al., 2017, 2015; Jemberu et al., 2022). These systems are broadly defined based on the integration of livestock with crop production, land availability, production intensity, type of product, agro-ecological zone, market orientation, household socio-economy, and livestock dependence (Gizaw et al., 2015, 2017; Notenbaert et al., 2009; Shapiro et al., 2017).

Working equids, however, have been largely excluded from such frameworks (van Dijk et al., 2014). The definition of livestock in UN food security policies has only included animals that produce food directly, like cows and sheep (Brooke, 2016). Mwasame (2020), notes that equid use and reliance has been consistently neglected in livestock policy documents throughout Africa. This is partly because working donkeys, horses and mules are generally excluded from the definition of “livestock” (Pritchard, 2014). Only recently, were working equids recognised for their contribution to global food security and formally recognised for their contribution to global food security through inclusion in the Committee on World Food Security’s definition of “working livestock” (Brooke, 2016; CFS, 2016). However, this recognition is inconsistently adopted at the national level, and there is still no systematic classification for working equids. Previous studies

attempted to classify the domestic equine population into broad categories such as working, racing, breeding, and leisure (Redmond et al., 2022), or based on their location such as rural, urban, and peri-urban (Admassu and Shiferaw, 2011; Asfaw and Tadesse, 2020; Geiger et al., 2021, 2020). Others have distinguished between those used for homestead activities and those used exclusively for commercial purposes (Valette, 2015). Additionally, some studies have applied typologies developed for other livestock species to working equids (Diop and Fadiga, 2021). None of the existing classifications provide a scientifically validated framework that can be used to measure equids economic contribution, their locally relevant disease burdens and specific local requirements that are needed to improve equid health and welfare.

Classifying and characterizing livestock production systems is key to understanding the burden of animal diseases. The burden of disease varies between livestock production systems due to differences in production purposes, breeds, management, and access to veterinary services. These factors all contribute to the risk of disease and the magnitude of losses (Rushton, 2009; de Glanville et al., 2020; Li et al., 2024). This study is part of the Global Burden of Animal Disease (GBADs) program, which seeks to deliver a consistent and comparable assessment of livestock diseases and their effects on production, animal welfare and human health across various animal production systems (Huntington et al., 2021; Rushton et al., 2021). This study is part of the Global Burden of Animal Disease (GBADs) program, which seeks to deliver a consistent and comparable assessment of livestock diseases and their effects on production, animal welfare and human health across various animal production systems (Huntington et al., 2021; Rushton et al., 2021). GBADs is developing a classification process to stratify livestock populations, economic value, and health-related impacts by production system (Li et al., 2024). The objective of this study was to classify and characterize working donkey classification systems in Ethiopia. Although working equids

includes donkeys, horses, and mules, this study focuses on donkeys, which constitute 81% of Ethiopia's equid population and are found across all agro-ecological zones (CSA, 2021a; Asteraye et al., 2024). Refined classification of the systems will enable an accurate reflection of resources used and produced by each system, thus allowing refined estimation of the burden of diseases in working donkeys. This will support context-specific needs assessments and effective interventions.

Materials and methods

Study area

Ethiopia is a GBADs case study country and has the largest working equid population in the world (CSA, 2021). This research was conducted in three districts sampled from the Oromia, Amhara, and Somali regional states of Ethiopia. These three regional states host the largest populations of working equids in Ethiopia, comprising over 80% of the country's donkey, horse and camel populations and over 60% of the country's mules (Asteraye et al., 2024). The study regions encompass a representative range of production systems found in Ethiopia.

Sampling strategy

Multistage stratified random sampling was used to select study households. First, 3 regional states and then 1 district per regional state were selected purposively based on the representativeness of the donkey population, agroecological zones, farming systems, and accessibility of the area. According to the Ministry of Agriculture's livestock production system classifications (CSA, 2021), the two districts from the Amhara and Oromia regional states were representative of crop-livestock mixed systems, while the district from the Somali regional state represented a pastoral production system.

Next kebeles within districts (next smallest administrative unit consisting of 13-21 villages), villages within kebeles and households within villages were selected randomly. A list of kebeles were obtained from the district agricultural office. A list of villages and households within kebeles were obtained from the kebele administration offices and key informants (for pastoral kebeles). The sampling approach and number of units selected at each level of sampling are shown in Supplementary Figure 1.

Data collection

A combination of primary and secondary data were used for this study. The primary data were collected through a structured questionnaire with face-to-face interviews with household heads from selected households between May and August 2022. The household questionnaire was carried out in conjunction with a related study aimed at estimating the economic contribution of donkeys and the burden of disease. Data were collected from a total of 435 households including those that owned donkeys (n = 244) and those that did not own donkeys (n = 191). For this study only the data from 244 donkey-owning households were used.

The household questionnaire contained questions regarding household demographics, income, donkey ownership and purpose to the household, donkey husbandry practices and health, and constraints of donkey ownership. Respondents were allowed to provide multiple answers where relevant; for example, they were able to indicate more than one purpose of keeping donkeys based on their utilisation. Trained enumerators conducted the interviews and recorded responses directly using the Open Data Kit (ODK) (<https://opendatakit.org>) Android platform and the geographic coordinates of the household location were captured using mobile GPS.

A pilot survey was conducted using twenty randomly selected households outside the selected study areas, in order to test clarity of questions, to make any necessary corrections and to estimate

the time needed to complete the questionnaire without causing distress for the respondent. The final questionnaire was administered in respective local languages (Amharic, Afan Oromo and Somali).

Environmental variables known to influence livelihood decisions, such as land cover, gradient, water availability, and working animal population density data were included in the classification process. These variables were extracted at the household-level from publicly available datasets ([Google Earth Engine script](#)) and central statistics agency of Ethiopia databases (CSA, 2021). Full details are provided in supplementary material table 1.

Data analysis

Production system classification

A two-step data-driven method was used to classify donkey keeping households, first the factors describing households were identified and used to score households (Multi Factor Analysis) and then households were grouped into clusters (Hierarchical Cluster Analysis) to maximise between cluster variability and minimize within cluster variability (de Glanville et al., 2020). This method allows identification of clusters of households that were similar in the way they kept donkeys, the challenges they faced and the resources they had available.

Multi Factor Analysis

Multiple Factor Analysis (MFA) is a multi-step process used to assess the relationship between variables that can be categorized into different groups (Escofier and Pages, 1994). This approach is suitable for datasets containing both qualitative and quantitative variables such as household questionnaire response data, where households are represented by groups of variables related to specific characteristics (Dehlholm et al., 2012; Pagès and Husson, 2014). MFA accounts for the

heterogeneity within groups of variables in terms of individual household characteristics and was used to identify the main variables and groups of variables that distinguished households by creating common factors for both.

Factor analysis can also involve the use of both active (A) and supplementary (S) groups of variables: Active variables are used to calculate the factors and define the factor space in which the factor analysis is performed, and supplementary variables are not used to define the factors but can be projected onto them. To apply MFA to the household questionnaire data, first, the list of variables thought to describe and differentiate between donkey keeping households were selected from the household survey data (n=57), based on researcher prior knowledge and consensus. Variables that describe the local geographical environment of the donkey keeping household were extracted for each household from publicly available GIS environmental datasets and Central Statistics Agency of Ethiopia (CSA) databases (n=13).

The 70 variables were split into eight groups for use in the MFA: local household environment (n = 13 (A)), donkey herd characteristics (n = 6 (A)), purpose of donkey keeping (n = 13 (A)), donkey husbandry and management (n = 10 (A)), household income (n = 10 (A)), constraints of donkey ownership (n = 10 (S)), and household demographics categorical (n = 5 (S)) and household demographics continuous (n = 3 (S)) (Table 1). Binary variables with less than 5% of households giving a positive response were excluded from the analysis to avoid variables with few observations or outliers dominating factor definitions and households with missing values to multiple survey questions were also excluded from the analysis (n=3).

[Insert Table 1]

To ensure all groups of variables had an equal *a priori* influence, all continuous variables (Group 1, 2, and 8) were standardized to have a mean of zero and a standard deviation of one before conducting the MFA.

The list of variables that describe household characteristics were then reduced into a set of orthogonal dimensions using MFA (Escofier and Pages, 1994), performed using the *FactoMineR* package (Lê et al., 2008) in R Studio using R statistical software version 4.4.0.

The number of factors retained from the MFA for interpretation was determined using the scree plot (Supplementary Fig 2), which indicates the eigenvalue of each consecutive factor as ‘large’ or ‘small’ based on the presence of a natural break (Costard et al., 2009; de Glanville et al., 2020). Only factors with large eigenvalues were retained for interpretation.

Hierarchical Clustering Analysis

Hierarchical (Agglomerative) clustering was performed using the *FactoMine R* package (Lê et al., 2008) in R, by calculating the Euclidean distance between points for each household on the two factors derived from the MFA that described most of the between cluster variation. Ward's method (WARD, 1963) was used to define clusters because it aims to minimise within-cluster variability and maximise between-cluster variability (Liu et al., 2010) which was the aim of this household classification process.

The average Silhouette Index (Rousseeuw, 1987), and a scree plot of inertia (sum of squared distance from point to cluster centroid) were used to evaluate clustering quality and validate results. These analyses were conducted using the using the silhouette R package in R package 4.4.0 (Maechler et al., 2024).

The clusters for each household characteristic were then compared statistically to the global mean for that characteristic using the v-test. A v-test value greater than 1.96 provides statistical support (i.e. p-value <0.05) for a difference in the mean of the variable in the cluster when compared to the population mean (Morineau, 1984).

Ethics Approval Statement

The respondents provided written informed consent to participate in the study. The study protocols, data collection tools, and consent procedures were approved by ILRI Institutional Research Ethics Committee (Certificate Ref. No: ILRI-IREC2023-11) in Ethiopia and by the external ethics committee of University of Liverpool (12578) as well as Brooke Animal Welfare and Ethical Review Body (AWERB) in the UK.

Results

Descriptive results

After removing entries with missing values, 241 donkey owning households were included in the analysis. Among them, 171 (70.1%) were from rural kebeles, 52 (21.3%) from peri-urban kebeles, and 21 (8.6%) from urban kebeles. Under previous livestock classifications 199 (81.5%) households would be considered crop livestock mixed and 45 (18.4%) would be classed as pastoral. Household socio-demographic characteristics including family size, education, type of household head and livelihood activities of the donkey owners are summarized in Table 2.

Multiple factor analysis

Study households were differentiated by five groups of active variables (Purpose, Environment, Husbandry, Herd and Income) using MFA. The greater the inertia (variance) of the variable groups on the first and second dimensions, the more the group contributes to the differentiation between households (Fig 1). The total variance explained by all variable groups on the first two dimensions

of the MFA was 24.5%: 14.02% by dimension 1 and 10.43 % by dimension 2. Dimension 1 was influenced primarily by the groups of variables related to the purpose of keeping a donkey (27.9%), donkey husbandry and management (23.9%), and household income (20.3%). Dimension 2 was mainly influenced by the groups of variables related to the purpose of keeping a donkey (25.2%), donkey herd characteristics (21.8%), and household environment (22.7%) (Fig 1).

[Insert Figer 1]

This result shows the significance of these variable groups in elucidating the variations observed among donkey keeping households. Cross contributions were observed, indicating that the contribution of individual variables varied across dimensions. This suggests that single variables could not be completely represented on a single dimension.

To describe the contribution of each variable to each dimension, variables were screened dividing 100 by the total number of variables ($N = 70$). Thus, any variable contributing greater than the average (1.4 %) percentage of the total variance described by that dimension is considered a significant contributor to between-household variation.

The top four categorical variables that contributed the most to the first dimension were households not earning income from selling crops (5.3%), used donkeys for transporting others' goods for business (4.2%), used donkeys as a pack (3.0%), and households earning income from selling firewood (3.0%). For continuous variables, the top five contributors to the first dimension were mule density (3.4%), donkey density (3.3%), number of donkeys aged less than 1-year (3.15%), number of male donkeys aged over 3 years (3.0%), and donkey working hours (2.6%) (Supplementary Table 2 and 3).

For dimension 2, categorical variables; household acquired a newborn foal (4.7%), owners treat their own sick donkeys (3.9%), using donkeys for breeding (3.8%), fully grazing feeding type (2.7%), and households not using donkeys to support cropping (2.4%), and continuous variables; number of female donkeys aged over 3 years (7.5%), number of donkeys aged less than 1 year (6.8%), number of donkeys per household (5.4%), annual vegetation cover (4.1%), and total annual precipitation (3.7%) contributed most to between household variation (Supplementary Table 1 and 2).

The median contribution of categorical variables to the variability of the first and second dimensions was 0.5 and 0.4, respectively, and continuous variables contributed 1.4 and 1.3 to the first and second dimensions respectively. The grouped variables that contribute greater than 1.4% on each of two dimensions are listed in Supplementary Tables 2 and 3.

[Insert Figer 2]

The positions of the variables in Figure 2 helps to illustrate the relationship between them and provides some visual evidence of clustering. For example, households that self-treat sick donkeys, do not use donkeys for transporting animal feed and cropping, and do not earn income from selling crop are closely correlated with negative values for dimension 1 and positive values for dimension 2.

Households that use donkeys for both unpaid and commercial activities, including transporting goods for business, as well as those using donkeys solely for commercial activities, are correlated with negative values for both dimensions 1 and 2. Other characteristics that are negative on both dimensions include households that purchase donkeys, undertake salaried work for income, primarily fodder-fed donkeys and use donkeys to pull carts or interchangeably as cart or pack

animals. There was a distribution of variables with a positive value for dimension one and both negative and positive values of dimension two. These are households that used donkeys for unpaid activities, transporting other's goods for business, supporting croppings, breeding, used donkeys as pack animals, and households that earn income from selling crops, local beverages, eggs, and firewood, as well as utilizing veterinary services for their sick donkeys.

Hierarchical cluster analysis (HCA)

The first two dimensions from the MFA (that explain 24.5% of the between household variance) provided the basis for HCA of the donkey-keeping households. The HCA conducted on MFA scores revealed the presence of three distinct clusters (Fig 3). The mean silhouette was width of 0.31, indicates moderately good clustering, and there was significant separation between the cluster centroids, showing that, on average, households were more closely related to households within their cluster than to households from other clusters.

[Insert Figer 3]

Three clusters were identified. Most variables mean cluster values were significantly different (t -test > 1.96) to the overall population mean values (Tables 2 and 3).

[Insert Table 2 & 3]

Cluster 1 – Domestic-Pastoral: Most households in this cluster kept donkeys for unpaid tasks, mainly transporting water, building materials, and goods to and from the market. Feed shortages and droughts were the major constraints for these donkey keeping households. These households were found in areas with low donkey population density, but a high donkey herd size compared to the other clusters, with high numbers of both male and female donkeys. Livestock are central to

livihoods in this cluster and income is rarely generated through other agricultural activities or product sales (Table 4).

Cluster 2 – Commercial: Households in this cluster predominantly used donkeys for income generation. Overloading and injuries were reported as the primary health and welfare challenges for these donkeys, with a higher proportion of households also reporting donkey mortality compared to other clusters. These households were in areas with high horse, and medium donkey, population density and donkey herd sizes were small; mainly composed of adult males. Most households in this cluster generated income by selling vegetables, livestock, and livestock products, as well as through salaried work (Table 4).

Cluster 3 – Domestic-Agricultural: Donkeys in this cluster were mainly kept for unpaid homestead tasks, such as supporting agriculture, transporting animal feed, and fetching water. Infectious diseases were identified as the major constraint on donkey health and welfare in this cluster. These households were located in regions with the highest donkey, horse and mule population densities. Donkey herds in this cluster showed a relatively balanced composition of adult males and females and they breed more than those in clusters 1 and 2. Livelihoods in this cluster primarily relied on cereals and cash crops production, with some additional income derived from livestock (Table 4).

[Insert Table 4]

The proportion of households, based on the existing 'Crop Livestock Mixed (CLM)' and 'Pastoral' classifications used for other livestock species, assigned to each of these three clusters is shown in Table 5. All cluster 1 (Domestic-Pastoral) households fall within the existing Pastoral classification and 7% of cluster 2 (Commercial) households would have previously been classed as pastoral. The

remaining commercial households and all cluster 3 (Domestic-Agricultural) households would have previously all been classed as CLM.

[Insert Table 5]

Discussion

A two-step multi-factor and cluster analysis was used to examine data on donkey owning households in Ethiopia to classify and characterize donkey production systems. The study identified three distinct systems described as Domestic-Pastoral, Domestic-Agricultural and Commercial. This classification of donkeys corresponds to some extent with the existing livestock and agro-ecology based classification (FAO, 2018b; Sere et al., 1995; Shapiro et al., 2017). However, this study also considered donkey purpose and demonstrates that this significantly influences how systems should be classified.

To the best of the authors' knowledge, this is the first study to apply a data-driven approach to the classification of production systems in Ethiopia. Similar to work done by (de Glanville et al. 2020) for livestock in Tanzania, use of this household data-driven approach revealed significant diversity in donkey production systems within relatively small geographical areas. The constraints reported by donkey owners varied between systems, underscoring the need for system-specific analysis of donkey health and welfare. The framework also serves as a basis for quantifying the economic burden of donkey diseases and welfare issues across systems and can be used to advocate for sufficient resource allocation to support these often overlooked and marginalised populations. This new framework also supports focused and specific monitoring of system changes by identifying key characteristics, constraints and use patterns unique to each production system, and also enabling assessment of owners' ability to manage and recover from current and future challenges. Understanding the true differences between donkey keeping systems, through use of this data

driven approach, is vital for developing targeted and effective interventions and monitoring processes that are locally relevant and system specific.

Donkey populations in arid pastoral areas of Ethiopia have significantly increased over the past two decades (Asteraye et al., 2024), playing a critical role in livelihood resilience and livestock production for these marginalized communities, as similarly found by Diop and Fadiga in Senegal (Diop & Fadiga, 2021). In the domestic pastoral system, donkeys rely primarily on grazing, and owners reported feed shortages and recurrent droughts as major constraints. The combination of an arid environment and cyclical droughts makes donkeys particularly vulnerable to nutritional stress and related disease (Watson et al., 2016; Niang and Kanyala, 2020). This study further shows that pastoral donkey owners often rely on self-treatment for sick animals. Similarly, Stringer et al. (2015) reported that, unlike other livestock, donkeys are excluded from routine vaccination programmes. Data from a related study also showed that donkeys in the pastoral system were not included in anthrax vaccination campaigns. These gaps in preventive healthcare substantially heighten health risks for donkeys in this system and could be targets for active intervention implementations for government or NGO outreach services.

Owners and donkeys in the commercial system were mainly found in peri-urban and urban areas. Donkeys in this system are primarily used for paid traction and transport services, providing their owners with a source of disposable income, and assisting with some domestic tasks. Thus, these donkeys not only contribute to household livelihoods but also act as a direct source of employment. This pattern is similarly observed in Senegal and India (Diop and Fadiga, 2021; Ravichandran et al., 2023). In urban and peri-urban areas grazing land is limited so donkeys are often partially or fully hand-fed with purchased feed. This means that these donkeys are not directly affected by

drought but they are likely to suffer nutritional, or digestive upset when local feed prices are high. Similar to findings by Geiger et al. (2023) and Admassu and Shiferaw (2011) owners in the commercial system predominantly kept male donkeys and reported overwork, overloading, and mechanical injuries as major constraints. This shows the need for system-specific interventions by animal welfare organizations to raise awareness of the impacts of inadequate nutrition and overworking and work with communities to improve the welfare of working donkeys.

The domestic agricultural production system, primarily found in the more equid dense rural crop producing highland areas of Ethiopia, was the largest of all systems identified from this study. Here households are often far from the nearest market with inadequate infrastructure and a lack of affordable transportation that hinders market access. Donkeys here provide the primary mode of transport for delivering farm products to the market and bringing back farm inputs. This is consistent with findings from (Admassu and Shiferaw, 2011; Geiger et al., 2023; Valette, 2015) and underscores the critical role donkeys play in supporting agricultural productivity and rural economies. Indeed, in Senegal owners with donkeys had higher crop production compared to those without (Diop and Fadiga, 2021). The domestic agricultural system donkeys also play a vital role in generating indirect income through firewood and charcoal sales, and local beverage production. These are key income sources for households and particularly benefit women. In an area often challenged with food insecurity and where women are amongst the most marginalised in society it is essential that good donkey health is considered in the support of sustained food production and women's economic stability. In this system, donkey owners reported infectious disease as the primary constraint to donkey ownership; thus, NGO's and local authorities could aim to improve disease management, through vaccination campaigns, training and knowledge exchange workshops for donkeys in this cluster.

Some limitations should be considered when interpreting these findings. While this study focuses on donkeys due to their large population and widespread distribution across the country, the classification developed may also broadly apply to other working equids, such as horses and mules. However, it is important to note that donkeys have some peculiarities that they are rarely used for riding, in contrast to horses and mules, which serve significant cultural functions, such as in weddings and funerals in certain communities. Moreover, unlike donkeys, distribution of horses and mules is limited mainly to the highland parts of the country. Therefore, we recommend that future research expand this framework to include horses and mules to achieve a comprehensive classification of working equids. Additionally, over 85% of surveyed households were male-headed, limiting the representation of women's perspectives and direct engagement with donkeys. Studies that purposively include female respondents are needed to capture gender-differentiated roles and constraints more fully. Finally, the terms 'Domestic-Pastoral', 'Domestic-Agricultural' and 'Commercial' may vary in characteristics and constraints in other regions and countries. Future research using similar methods to classify working equids in different areas would improve our understanding of livestock production diversity in Ethiopia and across sub-Saharan Africa.

Conclusions

This study conducted the first data-driven classification of donkeys in Ethiopia and identified three distinct systems. The three systems vary in purpose, management practices, herd characteristics, environmental factors and ownership challenges. The donkeys classification systems aligns to some extent with existing livestock and agro-ecology-based frameworks, suggesting that it could be integrated into current national livestock monitoring and policy systems without requiring structural changes. Such integration would facilitate rapid scaling, enabling policymakers and development agencies to incorporate donkey health and welfare monitoring into ongoing livestock

data collection initiatives, which is essential for effective assessment and intervention planning. Significant differences in production system characteristics underscore the need for targeted, system-specific interventions to address donkey health and welfare challenges that have potential to impact their owners' livelihoods. The results presented here will be used by the GBADs program and working equid welfare charity, Brooke, in a subsequent study to analyze population dynamics, the socio-economic contribution of donkeys in different production systems, and how disease and welfare issues affect donkeys and the people who rely on them. These studies will allow system specific estimates to be made and then used to inform more nuanced, tailored policies and interventions.

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531 Table 1: Variable and groupings used in MFA

Groups	Variables	Groups	Variables
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1.Local household environment (Active)	Distance to nearest road (Minutes) Distance to nearest market (Minutes) Distance to nearest water point (Minutes) Distance to nearest vet clinic (Minutes) Altitude Average annual daytime temperature (°C) Total annual precipitation (mm) Average slope (degrees) Average annual vegetation cover Local horse density (km ²) Local mule density (km ²) Local donkey density (km ²) Local camel density (km ²)	5.Household income (Active)	Income from crop sales Income from vegetable sales Income from livestock sales Income from milk sales Income from egg sales Income from local sales Income from animal feed sales Undertake salary work Firewood sale income Charcoal sale income
	2.Donkey herd characteristics (Active)	Number of donkeys owned per household Number of donkeys less than 1 year Number of donkeys between 1 & 3 years Number of male donkeys over 3 years Number of female donkeys over 3 years Average working hours per day (Minutes)	6.Constraints of donkey ownership (Supplementary)
3.Purpose of donkey keeping donkey (Active)	Fetching water Fetching firewood Transporting animal feed Transporting farm products to/from market Supporting cropping Transporting building materials Transporting other people’s good for Income generation Renting out Donkey sale Breeding use Borrowing and lending	7.Household demographics categorical (Supplementary)	Gender of respondent Household type Education level head
		8.Household demographics continuous (Supplementary)	Age of the Household head Household size Number of youth male Number of youth female Children
4. Donkey husbandry and management (Active)	Feeding type Separate barn Use vets Use traditional healers Use self-treatments Health cost Accessories cost Mode of donkey use Type of donkey acquisition Donkey purchased		

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534 **Table 2:** Percentage of households reporting variable presence for categorical variables in the
535 clusters derived from hierarchical cluster analysis (with 95% confidence interval)

Variables	Percentage of households reporting variable presence (n=241)			
	Overall percentage (95% CI)	Cluster 1 (n = 39)	Cluster 2 (n=87)	Cluster 3 (n = 115)
Purpose of donkey keeping				
Donkey kept for unpaid chores at home	70.5 (64.8-76.3)	75.3	37.0*	99.0*
Donkey kept for both unpaid & income generations activities	24.1 (18.7-31.0)	21.0	52.0	0.9*
Donkey kept for income generations activities	5.4 (2.5-7.7)	3.7	11.0*	0.0*
Fetching water	90.5 (86.7-94.2)	97.0	89.0	90.0
Transporting firewood	67.2 (61.3-73.1)	95.0*	57.0*	65.0
Transporting animal feed	70.1 (64.3-75.9)	10.0*	64.0	95.0*
Transporting farm products to/from market	73.0 (67.4-)	31.0*	80.0	82.0*
Support cropping	63.1 (57.0-69.2)	0.0*	61.0	86.0*
Transporting building materials	24.1 (18.7-29.5)	62.0*	24.0	11.0
Transport goods for business (cart service)	24.1 (18.7-29.5)	33.0	52.0*	0.0*
Renting out	5.8 (2.9-8.8)	10.0	11.0*	0.0*
Donkey selling	25.7 (20.2-31.2)	26.0	18.0	31.0
Breeding use	28.2 (22.5-33.9)	31.0	14.0*	38.0*
Social use (Borrowing/ lending with a neighbors)	71.4 (65.7- 77.1)	85.0*	51.0*	83.0*
Donkey husbandry and management				
Fully grazing donkey feeding	39.4 (33.2- 45.6)	67.0*	18.0*	46.0*
Partial grazing donkey feeding	54.8 (48.5- 61.1)	23.0	70.0*	54.0
Fully hand feed donkey feeding	5.8 (2.9- 8.8)	10.0	11.0*	0.0*
Separate barn	34.9 (28.8- 40.9)	7.7*	41.0*	39.0
Use veterinary services for healthcare	53.1 (46.8- 59.4)	18.0*	36.0	78.0*
Use traditional healers for healthcare	2.9 (0.8- 5.0)	0.0	6.9*	0.9
Use self-treating for healthcare	20.7 (15.6- 25.9)	87.0*	17.0	0.9*
Mode of donkey use-pack	60.6 (54.4- 66.8)	54.0	13.0*	99.0*
Mode of donkey use-pack & cart	20.3 (15.3- 25.4)	28.0	43.0*	0.9
Mode of donkey use-cart pulling	19.1(14.1- 24.0)	18.0	45.0*	0.0*
Household has donkey accessories	68.5 (62.6- 74.3)	74.0	59.0	74.0
Donkey acquisition - Purchase	62.2 (56.1- 68.4)	56.0	87.0*	45.0*
Donkey acquisition – born at home	24.1 (18.7- 29.5)	38.0*	1.1*	37.0*
Donkey acquisition - rent	0.8 (-0.3 - 2.0)	0.0	2.3*	0.0
Household income				
Crops	67.2 (61.3- 73.1)	7.7*	68.0	87.0*
Vegetables	21.6 (16.4- 26.8)	0.0*	54.0*	4.3*

Livestock	57.7 (51.4- 63.9)	69.0	43.0*	65.0*
Selling Milk	24.1(18.7- 29.5)	36.0	4.6*	35.0*
Selling Eggs	14.5 (10.1- 19.0)	0.0*	4.6*	27.0*
Selling local beer	18.7 (13.8- 23.6)	0.0*	5.7*	35.0*
Selling animal feed	5.4 (2.5- 8.2)	7.7	8.0	2.6
Undertake salary work	5.0(2.2- 7.7)	2.6	11.0*	0.9*
Selling firewood	14.1(9.7- 18.5)	0.0*	1.1*	29.0*
Selling charcoal	4.6 (1.9- 7.2)	10.0	1.1	5.2
Selling building materials	2.9 (0.8- 5.0)	13.0	2.3	0.0
Remittances	3.3 (1.1- 5.6)	0.0	1.1	6.2
Constraints of donkey ownership				
Diseases	67.2 (61.3- 73.1)	74.0	78.0*	57.0*
Feed shortages	31.5 (25.7- 37.4)	94.0*	39.0	30.0
Drought	12.9 (8.6- 17.1)	77.0*	1.1*	0.0*
Mortality	12.4 (8.3- 16.6)	36.0*	15.0	2.6*
Overloading and working	27.4 (21.8- 33.0)	15.0*	49.0*	15.0*
Mismanagement	22.8 (17.5- 28.1)	5.1*	44.0*	13.0
Mechanical injury	13.3 (9.0- 17.6)	10.0	25.0*	5.2*
Donkey theft	7.9 (4.5- 11.3)	7.7	17.0*	0.9*
Other problems	5.8 (2.9 - 8.8)	5.1	6.9	5.2
Household demographics – categorical variables				
Male headed household	85.1 (80.6-89.6)	92.0	94.0	76.0
Head completed primary school and above	14.5 (10.1-19.0)	2.6*	33.0*	4.3*

¹ 95% confidence interval given in parentheses.

*v-test value > 1.96 representing statistically significant (p-value <0.05) difference between cluster mean and overall mean.

Table 3: Mean (and median) values for continuous variables for households within the clusters derived from hierarchical cluster analysis.

Domains/Variable	Mean (Median)			
	Overall (n = 241)	Cluster 1 (n = 39)	Cluster 2 (n=87)	Cluster 3 (n = 115)
Local environment				
Distance to nearest road (Minutes)	27.3 (20)	46.8*	17.1*	28.4
Distance to nearest market (Minutes)	66 (60)	69	61	70
Distance to nearest water point (Minutes)	32.8 (30)	50.0*	26.1*	32.1
Distance to nearest clinic (Minutes)	51.8 (45)	80.5*	44.7*	47.3*
Altitude (Meters)	2318 (2200)	1513*	19601*	28612*
Average annual day time temperature (°C)	34 (34)	39*	36*	32*
Total annual precipitation (mm)	779 (843)	278*	803	931*
Average slope (Degrees)	5 (3.3)	1.3*	2.3*	8.3*
Average annual vegetation cover	0.3 (0.3)	0.1*	0.3	0.3
Local Horse density (km ²)	11 (10)	0.0*	13	11
Local mule density (km ²)	0.5 (0.3)	0.0*	0.3	0.8*
Local donkey density (km ²)	32(22)	4.5*	22*	49*
Local camel density (km ²)	1.2(0)	7.1*	0.2*	0*
Number of donkeys per household	1.8(2)	2.2*	1.5*	1.8
Donkey herd characteristics				
Number of donkeys less than 1 year	0.2(0)	0.3	0.0*	0.3
Number of donkeys between 1 &3 years	0.3(0)	0.3	0.3	0.3
Number of male donkeys over 3 years	0.9(1)	1.0*	1.0	0.7*
Number of female donkeys over 3 years	0.4(0)	0.6*	0.2*	0.5*
Donkey working hours per day (Minutes)	197(180)	195	239*	166*
Household demographics – continuous variables				
Age of household head	45.9(45)	47.6	38.7*	50.7*
Size of the household	5.8(5)	8.0*	6.4*	4.5*
Number youth male	1.3(1)	2.3*	1.1*	1.2
Number youth female	1.0(1)	1.6*	0.7*	1.0
Number children	1.8(1)	2.1	2.9*	0.8*

549 **Table 4:** Summary features of the three-cluster identified for working donkeys

Feature	Cluster 1	Cluster 2	Cluster 3
	<i>Domestic-Pastoral</i>	<i>Commercial</i>	<i>Domestic-Agricultural</i>
Donkey	Unpaid household activities by pack (e.g. fetching water, building material for transhuman) Livestock are central to livelihoods Donkeys grazed and kept in larger herds. Homebred. Owners treat their own sick donkeys. Food shortages and drought main health and welfare concerns.	Transporting goods and people by cart for a fee. Some households reported renting out donkeys. Kept in barns and fed fodder. Donkeys usually bought. Use veterinary services. Overloading and injury main health and welfare concerns, high mortality compared to other clusters.	Primarily unpaid household activities but also used to support agricultural and crop production. May also be used to transport firewood, straw or local beverages by pack for sale for additional personal income. Cereals and cash crops are priority Donkeys partially graze with some fodder. Use veterinary services. Injury and disease are the main health and welfare concerns.
Households	High average travel time to roads, markets, water and veterinary clinics Had large family sizes and were without formal education beyond primary school	Located closer to the nearest road, water point, and veterinary clinic. Households were headed by individuals with at least a primary school education	High average travel time to the market and water and vet clinics Households were mostly headed by individuals with little to no formal education beyond primary school.
Environment and other working Livestock	Located in areas of higher average temperature, low average vegetation cover, low level of annual rainfall and low average slope. Found in areas with the highest average camel population density, and no horse or mule populations	Located in areas with moderate vegetation cover and temperature compared to the study area's average. Found in areas with the highest horse population density and medium donkey density.	Located in areas with relatively high annual rainfall, higher vegetation cover, higher slope, and low average temperature. Found in areas with the highest donkey, horse and mule populations and no camels.

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551 **Table 5:** Comparison of household cluster to the production system.

Production system classifications	Cluster 1 (n = 39)	Cluster 2 (n=87)	Cluster 3 (n = 115)
Crop livestock mixed (n=199)	0(0%)	84(42.2%)	115(57.8%)
Pastoral (n=42)	39(92.9%)	3 (7.1 %)	0(0%)

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