Small Ruminant Research 229 (2023) 107114

Contents lists available at ScienceDirect

Small Ruminant Research

journal homepage: www.elsevier.com/locate/smallrumres

Goat health and management for improved smallholders' livelihoods in central Malawi – A socioeconomic analysis of rural households

Paul M. Airs [a], Javier Ventura-Cordero [a], Lovemore C. Gwiriri [b,c], Jonathan H.I. Tinsley [a], Winchester Mvula [d], Michael R.F. Lee [e], Jan A. van Wyk [f], Patson C. Nalivata [d], Taro Takahashi [b,g,1], Eric R. Morgan [a,*,1], Andrews C.L. Safalaoh [d,1]

[a] Institute for Global Food Security, Queen's University Belfast, Belfast, Northern Ireland, United Kingdom
[b] Department of Sustainable Agriculture Sciences, Rothamsted Research, Okehampton, Devon, United Kingdom
[c] Centre for Agroecology, Water and Resilience, Coventry University, Coventry, UK
[d] Animal Science Department, Lilongwe University of Agriculture and Natural Resources (LUANAR), Lilongwe, Malawi
[e] School of Sustainable Food and Farming, Harper Adams University, Newport, Shropshire, United Kingdom
[f] Department of Veterinary Tropical Diseases, University of Pretoria, Pretoria, South Africa
[g] Agri-Food and Biosciences Institute, Hillsborough, Co. Down, Northern Ireland, UK

ARTICLE INFO

Keywords:
Food security
Livelihoods
Plant supplementation
Small ruminants
Ethnobotany

ABSTRACT

The true value of goats, their management systems, and the limitations of smallholdings have not been fully explored in the context of sustainable livelihoods among rural smallholders in central Malawi. However, goats are an essential part of rural livelihoods as transferable assets and sources of household nutrition, especially at times of food insecurity aligned to an ever more variable climate. To study the impact and limitations of goat ownership in Malawi's Lilongwe district, surveys were performed across four villages covering 148 households from October-November 2019. Surveys were designed to identify linkages between household demographics, livelihoods, goat ownership, and management practices. Findings revealed goats are highly valued compared to other livestock. However, herds were small (median = 3) with only 62% reported kidding in the last year, while 50% reported deaths due to diseases, predation (such as by hyenas), and dog bites. Odds-ratio analyses identified farmers (as a primary occupation) were more likely to successfully breed goats to increase their herd size. Larger herds were associated with those who could accumulate wealth and utilise goats for ceremonies. However, diseases were a major contributor to losses and increased the risk of household food insecurity. Limiting disease impacts through anthelmintics and supplementation were correlated to an increased likelihood of sustainable offtake from smallholdings and improved livelihoods. With limited access to veterinary services, smallholders utilise a diversity of medicinal plants and ash to treat diarrhoea in their herd. The results highlight that goat security and health is fundamental to realising smallholding livelihood gains. Future efforts should aim to empower smallholders through providing tools to monitor goat health and to assess the effects of local practices, including the use of medicinal plants, for goat health.

1. Introduction

Goat smallholdings are inextricably linked to rural life in Malawi as a source of meat, milk, manure, and skins, and provide a route to improved livelihoods as a tradeable asset (Freeman, 2008; Gwaze et al., 2009). Goats have proliferated as assets in Malawi, where the national goat population has risen from 631,000 in 1993 (Banda et al. 1993), to 1.9 million in 2008 (Freeman, 2008), to 11.6 million in 2021 (FAOSTAT, 2022). Goats are common in rural areas, owned across 90% of rural households (Freeman, 2008). This study found food insecure Malawian households own less goats on average (0.3 goats) compared to neighbouring regions such as Lesotho (10 goats) and Zambia (4.3 goats). The same was true for food secure households, with Malawi averaging two goats per household compared to Lesotho (30 goats) and Zambia (4.3 goats). Despite this, a recent study of Malawi smallholder cooperatives found goats can contribute towards ~25% of household income and

* Corresponding author.
E-mail address: eric.morgan@qub.ac.uk (E.R. Morgan).
[1] These authors contributed equally.

https://doi.org/10.1016/j.smallrumres.2023.107114
Received 9 June 2023; Received in revised form 27 September 2023; Accepted 10 October 2023
Available online 12 October 2023

~60% of total livestock income in rural areas when larger herd sizes can be achieved (6–20 goats) (Kaumbata et al., 2020). Regardless of herd size, smallholdings act as risk management and coping strategies whereby goats are sold in cases of emergency, food insecurity, or for general household expenditures such as school fees (Freeman, 2008; Kaumbata et al., 2020). In Malawi, ~50% of the population face severe food insecurity (2014–2021), twice that for the average of the sub-Saharan Africa region (FAO et al., 2020). Therefore, goat smallholdings can positively impact livelihoods, but the ability for goats to buffer against food insecurity requires further study in Malawi.

The potential positive impacts of goats may be limited by a number of factors linked to goat management practices typical of smallholdings in southern Africa. For instance, in pastoral foraging and grazing systems, goat losses are high and are driven by multiple factors such as: malnutrition and death caused by gastrointestinal nematode parasites (Bath et al., 2016; Qokweni et al., 2020), predation (Chikagwa-Malunga and Banda, 2006), and theft (Sidebottom, 2013). While preventing goat losses is pivotal to maintaining livelihoods, management practices are often put in place out of necessity. For smallholders in Malawi, who rely principally on crop production (Freeman, 2008; Kaumbata et al., 2020), goats are often tethered to prevent crop destruction (Banda et al., 1993; Gwaze et al., 2009). Tethering without proper supplementation leads to poor goat nutrition (Caldeira et al., 2007; Muir et al., 1995), which reduces growth and subsequently reduces goat price at market (Bath et al., 2016; Gwaze et al., 2009; Kaumbata et al., 2020). When goats are released from tethering to communal grazing areas for open-range grazing, conditions are not much better as these tend to be overgrazed, leading to the spread of parasites and limited forage, which results in reduced meat and milk yields, even in hardy indigenous Malawi goats (Banda et al., 1993). Beyond management, there is a need to improve marketing and policies surrounding marketing of goats, especially in relation to formation of co-operatives to improve fair pricing (Banda et al., 1993; Haile et al., 2011; Gwaze et al., 2009; Kaumbata et al., 2020; Roets and Kirsten, 2005). Formation of cooperatives has proven that goat smallholdings can be both profitable and resilient, providing income, insurance against disasters such as crop failure brought on by drought, and acting as a credit buffer (Kaumbata et al., 2020). However, the extent to which cooperatives can be self-sustaining for food insecure households has yet to be determined.

Improving current household livelihoods through goat ownership must also account for the reality faced by those living under the threat of food insecurity as well as the nature of the climate itself. For instance, there are efforts to improve smallholding performance through the introduction of exotic breeds, but these tend to suffer from increased kid and adult mortality in the face of harsh climates and high parasite burdens compared to local breeds (Banda et al., 1993; Nguluma et al., 2022), and are less adapted to available sources of nutrition (Silanikove, 1986). Recently, breeding programs have turned to small East African local breeds in Malawi and neighbouring countries (Kaumbata et al., 2021, 2020; Nguluma et al., 2022). For community-based breeding programs in Mzimba (Northern) and Nsanje (Southern) regions of Malawi, kid sex ratio, kid survival, twinning rate, and doe size were the most valued characteristics (Nandolo et al., 2016). However, pursuing these characteristics does not guarantee positive impacts on smallholder livelihoods, with many programs resulting in failure (Kosgey et al., 2006). Alternatively, policies can focus on managing goat losses by limiting diseases such as gastrointestinal nematode infections, but this approach also requires improved access to veterinary services (Gwaze et al., 2009; Monau et al., 2020). While improved infrastructure and access to veterinary care would be most beneficial, a more immediate alternative may be to provide farmers with tools and education to reduce disease risks and monitor nutrition themselves. This has been witnessed already in targeted selective treatment (TST) programmes using low resource methods such as the Five Point Check©, which manage goat health with minimum inputs yielding a net positive impact of goat ownership (Bath and van Wyk, 2009; Sargison et al., 2021; Walker et al., 2015).

While efforts are being made to improve goat health and production in Malawi, it is critical to assess the relationship between different limitations preventing sustainable goat production at the individual smallholder level, as well as to identify factors underpinning smallholding success. The overarching objective of this study was to investigate socioeconomic factors associated with limiting or strengthening goat smallholding in resource-poor settings in Malawi. To this end, a questionnaire was designed to observe aspects of smallholdings and their limitations in the context of household livelihoods in rural villages of central Malawi. Specifically, we aimed to identify limitations of keeping goats alongside factors associated with success. Goat ownership and management practices were analysed with respect to capital goods ownership and food security. Food security was measured through number of meals taken per day for adults and children, in addition to whether the household worried about food in the last seven days. By generating a profile of individual households, we sought to better understand contextual socioeconomic factors at the household level which may limit or advance smallholder goat production to aid future policy and intervention development related to goat production.

2. Materials and methods

2.1. Study area

The study area included Mkwinda, Kamchezera, Mazinga, and Chikhowe villages in central Malawi's Lilongwe District, an area with a wet tropical climate with conditions typical of rural areas in the wider region. Lilongwe district was chosen for the study due to the considerable prevalence of goat ownership and is the largest district in Malawi with a population of 1.64 million in 2018 (GoM National Statistical Office, 2018).

2.2. Ethics statement

Surveys included in the study and the manner of collecting survey responses were reviewed and approved by the Animal Science Department Ethics Committee at Lilongwe University of Agriculture and Natural Resources (LUANAR). Informed consent for study participation was performed prior to survey collection with the objectives of the study explained. All participants were informed that they were free to drop from the study at any time and consent was obtained through signatures for literate participants or verbally declared in the presence of LUANAR team members for illiterate participants.

2.3. Study design and objectives

Two versions of a questionnaire were designed to assess factors relating to goat ownership and goat health, as well as to observe livelihood traits of households. Demographic information including age, education level, and income sources were included in both versions. Many questions pertain to the household and not the individual respondent and were included in both versions of the questionnaire, as were livestock ownership, management, current limitations, and questions about plant use in relation to goat health and nutrition. Version 1 of the questionnaire included additional details relating to plant use for supplementation and medical uses. One survey question was included as part of a wider study on goat health and was not included in this analysis, this question was Version 1 Question 6 ("Can you name 5 readily available (frequent) and 5 less available plants in the area where the goats graze."). Version 2 of the questionnaire was expanded to include additional household information including: the number of meals eaten by household members per day, the ownership of capital goods in the household, and the ability to make savings from current income.

2.4. Selection of respondents

Individuals from households in the study area were approached in accordance with the ethics statement above and asked to participate in the study. Respondents were selected based on their ownership of goats. The sample size was determined by the number of individual households available within a reasonable timeframe following permission from the Group Village Head. To ensure consistent recordings, responses were limited to a small number of researchers fluent in both Chichewa and English with at least one native Chichewa speaker and one native English speaker present during the course of each questionnaire.

2.5. Data collection

Version 1 was recorded during October 2019 in Mkwinda with 48 respondents. Version 2 was recorded between October–November 2019 across four village areas (Mkwinda, Kamchezera, Mazinga, and Chikhowe) with 100 respondents. Respondent names were collected to prevent repeat responses and were anonymised in available data but were excluded from further analysis. Responses were collected in English or translated to Chichewa by research team members fromthe Lilongwe University of Agriculture and Natural Resources. Upon surveying and during follow-up field research, images collected in the same area surveyed are presented here for illustrative purposes. Complete anonymised raw data are shown in S1 File.

2.6. Data management and analysis

Survey responses were tabulated (see S1 File) and formatted in Excel (Microsoft Inc., Redmond, Washington, USA) with statistical analyses and graphical representations generated in GraphPad Prism version 9.4.0 for Windows (GraphPad Software, San Diego, California USA, www.graphpad.com) or in R version 4.2.0 "Vigorous Calisthenics". Blank fields where no response was given were not included in analyses. In some instances, a categorical response (i.e., "yes" or "no") was provided in response to a question where a numerical answer was expected. In these instances, a value of 1 was given for "yes" responses and a value of 0 was given for "no" responses.

Contingency analysis to calculate odds-ratios (OR) were performed across the dataset with four main questions selected as categorical variables for comparison (see S2 Table). For these analyses, each variable was a question response split into a binary case. Questions with numerical responses were divided into "More/Less" where a $>$ median response = "More" and a $\leq$ median response = "Less". Questions pertaining to presence or absence were organised as "Yes/No" where "yes" or any ‡ 0 numerical response = "Yes" and a 0 or "no" response = "No". Ranked questions were organised in to "Rank 1″ where the highest rank = Rank 1 vs all other ranks given. All ORs were calculated with the with Baptista-Pike method and Fisher's exact test. All questions were considered as variables and were tested against four main categorical variables including: births in the last 12 months (yes vs no), deaths last 12 months (yes vs no), goats owned ($>$ median vs $\leq$ median), and food worry in the last 7 days (yes vs no).

3. Results

3.1. Smallholder household demographics

Households ranged from 1 to 10 year-round members (median 5) and up to 5 seasonal members (0–5, median 1). Respondents were almost all literate in Chichewa (96%), with English (18%) and other languages less common. Both age and gender of respondents were approximately equally distributed between females (n = 76) and males (n = 72) over the age of 30, with no other genders reported (Fig. 1A). No significant differences between gender and age were identified (Wilcoxon matched-pairs signed rank test, p = >0.9999), with fewer but insignificant responses from younger persons (Kruskal-Wallis test with exact P value, p = 0.0836) as responses were primarily collected from household heads. There was no significant interaction between age and education level (Fig. 1B), but education levels were not equally distributed, with primary education (62%) being the highest level of education for most respondents (Friedman test, p = 0.0109). Almost 80% of respondents were married with the remaining divorced (12.5%) or widowed (8.33%). While the survey accounted for households rather than individuals, respondents were largely represented by married adults fluent in Chichewa with some childhood education. Table S1 in the supplementary materials displays demographic characteristics of respondents.

3.2. Smallholder livelihood assessment and moveable assets

Livelihoods were assessed through income, capital ownership, and food security. Primary income was predominantly from farming (68.2%), compared to employment (17.5%) and those without an occupation (14.2%) (Fig. 2A). Second and third ranked income sources were more mixed between business ownership, employment, farming, and other means (Fig. 2B). Income generated was typically insufficient, with only 12% earning enough to build savings. Of the remaining responses, 75% could 'only just meet expenses', 4% had to supplement income with existing savings, and 9% stated both income and loans were needed to meet expenses. However, no discernible differences between number of income sources and ability to meet expenses were identified (Kruskal-Wallis test with exact P value, p = 0.5044). There was also no discernible difference between income source and ability to build savings.

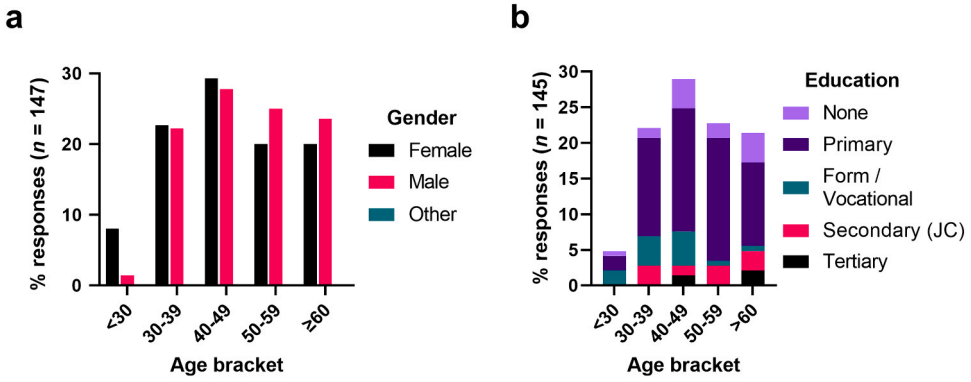

Fig. 1. Principal demographics of survey respondents. (a) Distribution of gender by age groups, respondents were evenly divided between males and females (Wilcoxon matched-pairs signed rank test, p = >0.9999), with the majority of responses coming from those over 30 years of age. (b) Distribution of education level by age group shows equal distribution across age groups, with a significant majority having reached primary education (Friedman test, p = 0.0109).

Fig. 2. Sources of income. (a) Main occupation or other income sources of respondents. (b) Secondary and tertiary sources of income. 'Farmer' category includes farming and agriculture, 'Other / Not-employed' category includes remittance, pension, benefit, and gift income.

A lack of ability to build savings was reflected in limited capital goods ownership, with 22% of respondents lacking ownership of any goods listed and 47% with only one item (Table 1). Very few households had multiple goods across multiple categories (3%), with no people owning more than 7/9 of the different goods listed. The median number of goods owned was two across two categories.

When surveying food insecurity, 41% of respondents reported that, in the past seven days, they had worried that their household did not have enough food. Meals per day ranged from 1 to 3 for adults (median = 2) and 1–4 for children (median = 3). Children were always provided the same (87.6%) or more meals (12.4%) per day, compared to adults. Households where respondents worried about having had enough food in the past 7 days ate fewer meals per day than those who were not worried ($p = 0.0497$, Mann-Whitney test).

Assessing the importance of different livestock revealed that goats were more numerous than other species kept, namely chickens, pigs, and cattle (Table 2, Kruskal-Wallis test with multiple-comparisons, $p < 0.0001$). Goats were also ranked highest in terms of importance to the household, with chickens most frequently ranked second (Table 2). Smallholder families typically owned the goats they keep with the household head (83% of respondents) and other family members (12% of respondents) making up the majority of owners, excepting for ownership by unrelated employers (2%) or herders (2%). The breed of goats per farm was universally reported as "local" by respondents when asked what breeds were kept on their farm, indicating a lack of exotic breeds. Goats and other species were kept with a median of 2/8 livestock species per smallholding (Table 2).

Herds were small with a median of 3 goats (range 1–14), with adult females (97% of respondents), kids < 1 year of age (42% of respondents), and suckling kids (33% of respondents) most frequent (Table 3). When asked about the objective of owning goats as an open-ended question in version 1 of the survey, 94% responded that goats "help farming" and that the importance of farming goats was for "help in a time of need" (91.6%) or "help with basic needs" (6.25%). In version 2 of the survey question responses were provided as a ranked list, as 'help in time of need', 'meat', 'milk', 'savings', and 'other' in relation to goat ownership. 'Help in time of need' was ranked highest (rank 1 for 62% and rank 2 for 15% of respondents) and 'savings' most commonly second in importance (rank 1 for 28% and rank 2 for 52% of respondents). Meat, milk, and other reasons were limited, with the next most common factor being 'manure' as a volunteered (write-in) response (rank 1 for 5% and rank 2 for 3% of respondents). The ranking of the importance of 'manure' may have been higher if it was included as a specific option in the questionnaire.

Small herd sizes were uniformly due to limitations in farming and resources with 100% of respondents wanting to increase their herd size if possible. In version 1 of the survey, respondents were asked to define productivity of their stock with 46/48 respondents answering "twins" or "triplets" indicating reproductive rate as the primary characteristic for goat production. Milk availability (n = 14/48) and meat yield (n = 4/48) were other less frequently offered characteristics of productive animals.

New stock was acquired on 70% of smallholdings within the last 12 months, with births (62% of respondents) being the primary source (Table 3). Losses of goats typically outweighed new stock brought in, resulting in a net loss of goats in the past year (median −1). Death of adult goats or kids (50% of respondents) was the most common cause, resulting in a total loss in investment, while consumption (1%) was rare (Table 3). Sales (27%) were the second most common reason for removal of goats from the farm, followed by use for consumption at ceremonies such as weddings and funerals (12%). Reasons for sales were diverse and included "to buy food" (n = 6), "to have money for medical treatments" (n = 1), "to buy fertiliser" (n = 5), "to pay school fees" (n = 6), "to pay family expenses" (n = 3), "for house construction" (n = 3), and for others, but were mostly to pay for ongoing costs and not to grow income or save.

Table 1
Capital goods ownership per household.

Item	Ownership (%)	> 1 of item owned (%)	Maximum owned (n)
Bicycle	56	6	3
Car	2	1	2
Donkey / Ox cart	9	2	3
Fridge / Ice box	2	2	3
Mobile phone	55	4	5
Motorbike	6	0	1
Radio / TV	36	5	3
Sewing machine	5	0	1
Wheelbarrow	9	2	2
Any items[a]	78	53	13
Different items[b]	NA	3	7/9

[a] Ownership of any of the items listed in the table. [b] Number of different items owned within the same household, NA = Not applicable.

3.3. Goat management practices in the study area

A seasonal management strategy was reported for the majority of smallholders with goats allowed to freely graze or browse in common grassland ('dambo') environments during the dry season and tethered close to houses during the rainy season (Fig. 3A). Most goats were housed during the night, many kept within the household itself, and some in raised khola structures (noted during survey collection by authors but not tabulated). Common grazing areas such as a dambo (a grassy floodplain or common grazing area) were mentioned frequently during the rainy season with some farmers allowing goats to free graze all-year-round (n = 5/100 for adult goats), while others kept goats tethered all-year-round (n = 6/100 adult goats). No statistical differences between goat deaths and the practice of tethering during the day

Table 2
Household livestock ownership and ranked importance to household.

	Cattle	Chicken	Donkey	Duck	Goat	Pig	Rabbit	Sheep	Different livestock[a]
Ownership (%)	9.5%	60.8%	3.0%	8.2%	99.3%	25.7%	3.1%	1.0%	NA
Minimum	0	0	0	0	0	0	0	0	0
25% Percentile	0	0	0	0	2	0	0	0	1
Median	0	3	0	0	3	0	0	0	2
75% Percentile	0	7	0	0	5	1	0	0	3
Maximum	7	39	6	7	14	52	8	7	6
Ranked 1st [b]	2%	6%	2%	0%	78%	13%	0%	0%	
Ranked 2nd [b]	6%	49%	0%	2%	13%	7%	0%	0%	

[a] Number of different livestock species owned, [b] Ranks are from 'relative overall importance to household' with many providing only a 1st rank and 1 respondent giving a 1st rank to two different livestock.

Table 3
Household changes in goat ownership over last 12-month period.

Status	Type or Reason	%[a]	Min	Median	Max
Currently owned	Adult female	97	0	2	8
	Adult buck	12	0	0	5
	Castrated male	4	0	0	2
	Kid (< 1 year)	42	0	0	4
	Kid (suckling)	33	0	0	4
	Any	100	1	3.5	14
Brought in	Born from owned stock	62	0	1	9
	Exchanged	4	0	0	1
	Gifted adults	0	0	0	0
	Loans	0	0	0	0
	Purchased adults	6	0	0	1
	Purchased kids	1	0	0	1
	Any	70	0	1	9
Removed or lost	Consumed at ceremonies	12	0	0	3
	Consumed domestically	1	0	0	1
	Death of adults	43	0	0	7
	Death of kids	14	0	0	7
	Death of adults and/or kids	50	0	0.5	10
	Gifted	2	0	0	1
	Sold	27	0	0	7
	Any	78	0	1	14
	Net change[b]		-8	-1	4

[a] Proportion of respondents in survey version 2 (n = 100), [b] Net change calculated as number of goats brought in vs number of goats removed in last 12-month period.

were identified (tethered vs free grazed goats during day, Mann-Whitney Two-tailed test, p = 0.6048). Tethered goats were generally provided with some form of basal ration (feed) or supplementation on 86% of smallholdings (Fig. 3B-C). Grain (n = 73/100) and foliage (n = 68/100) were most frequently provided in unknown volumes and at unspecified times to goats. Of the remaining farmers, 14/100 respondents provided no supplementation listed, and 6/100 stated that grazing constituted the only nutritional source for their goats.

3.4. Constraints to livestock farming in the study area

When asked to define limitations to goat production, diseases and dog bites were the predominant reasons reported (Fig. 4A). Similarly, 54% of goat deaths in the last 12 months were ascribed to predation by wild animals or dog bites, and 34% reporting disease (Fig. 4B). Other reasons for goat deaths were attributed to injuries from either hardware, i.e., foreign body ingestion (n = 2/50), or poisoning (n = 1/50). When asked to categorically rank limitations on herd size, 'cash to buy' and 'predation/dog bites' ranked the highest in importance, followed by diseases (Fig. 4C).

Reasons for treatment of goat health conditions were mixed but limited in number, with internal parasites (commonly referred to as 'worms') treated with drugs or anthelmintics by 1/3rd of respondents (Fig. 5A). As regards diarrhoea, commonly reported as a reason for death (8/50), respondents resorted to wood ash as a primary means of treatment in addition to anthelmintics and ethnobotanicals (Fig. 5A).

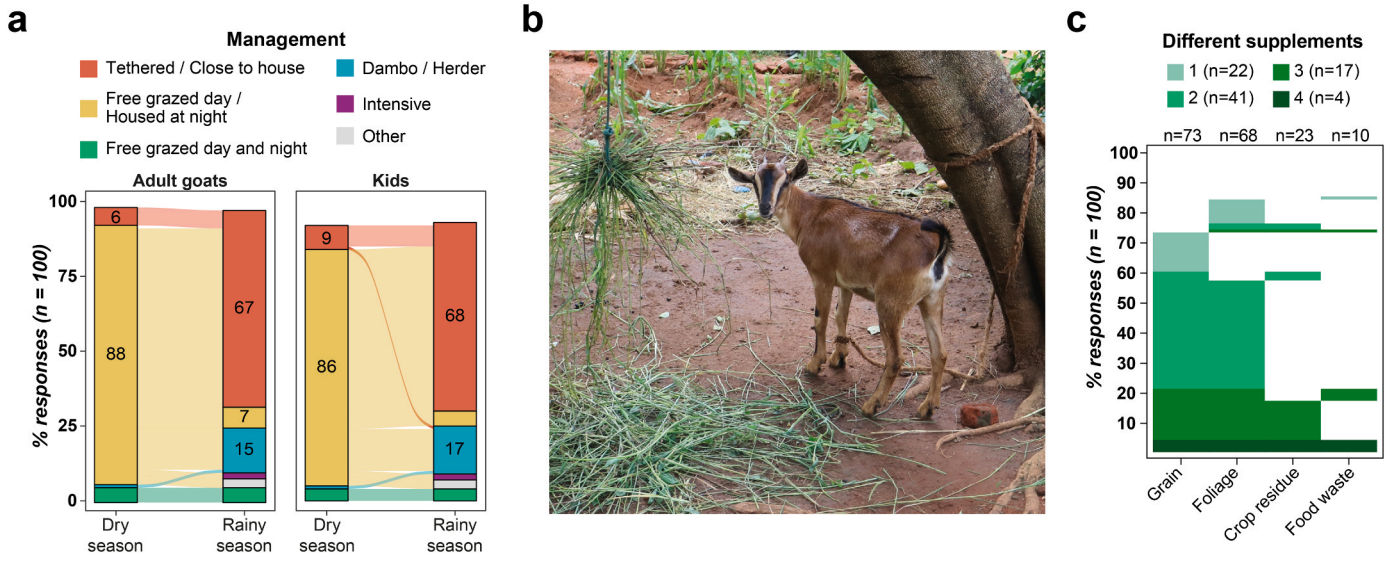

Fig. 3. Goat management strategies. (a) Alluvial plotted shifts in management practices between dry and rainy seasons for adult goats and kids. Flows indicate change in management between dry and rainy seasons for each age category. For example, of the 6% of respondents tethering adult goats in the dry season, all of them do so also in the rainy season together with many of those who free-grazed goats in daytime in the dry season. Write-in responses included 'Dambo / Herder', 'Intensive' and others. Proportions > 5% shown. (b) Image of tethered goat receiving food ration, some goats are tethered within reach of forage and are additionally supplemented. (c) Heatmap of supplements provided to goats separated by type of supplementation and number of different supplementation types provided.

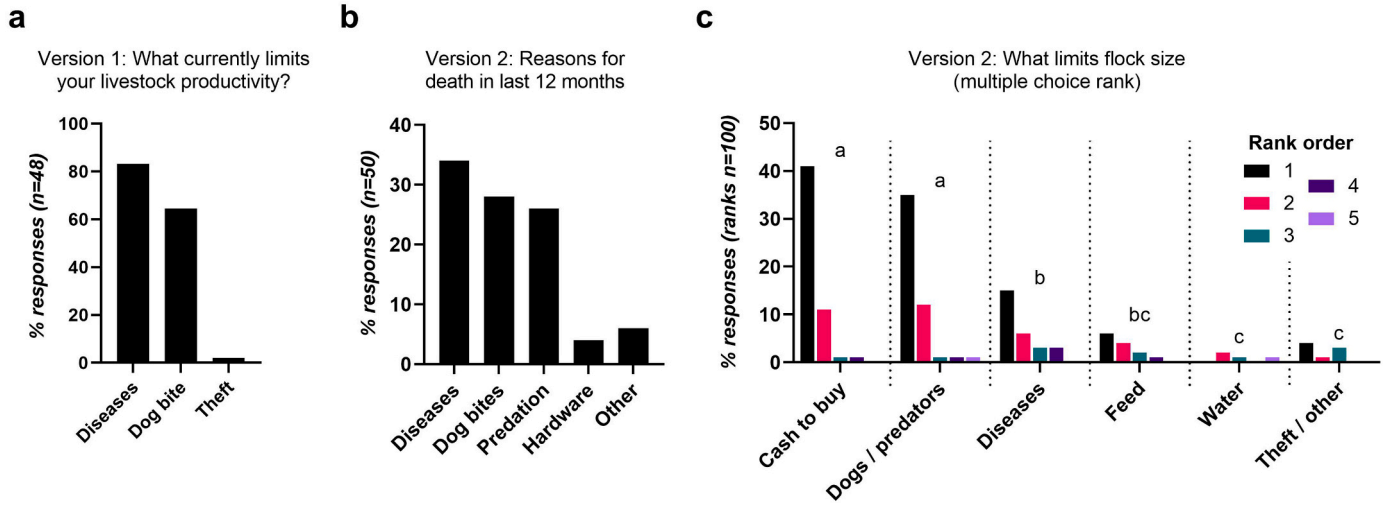

Fig. 4. Limitations to goat smallholdings. (a) Limitations to livestock productivity, with survey version 1 comprising open ended field responses. (b) Reasons listed for goat (adult and kid) deaths over the last 12 months, survey version 2 open ended field. (c) Rank choice limitations of goat herd size, survey version 2 multiple choice question with Dunn's multiple comparisons test for sum rank orders post Kruskal-Wallis with statistically significant grouping ($p < 0.05$).

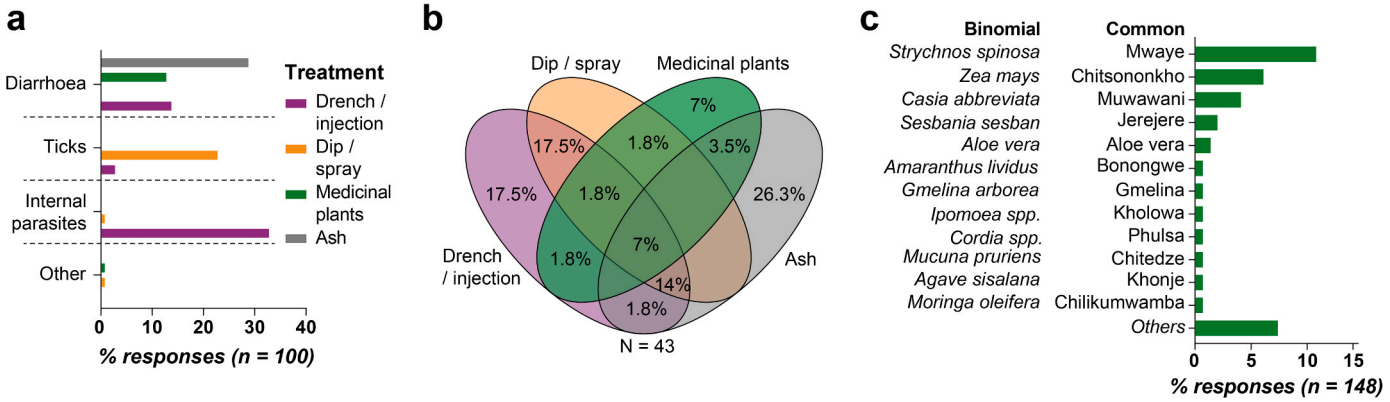

Fig. 5. Treatments for goat health conditions. (a) Treatment types provided for different goat health conditions. Internal parasites included 'worms' as a write-in response and ash was included as a write-in category. (b) Four-way Venn diagram of treatment types used per respondent. (c) Most commonly mentioned plant species used in treatment of goat ailments with common names in Chichewa and Latin binomials given. 'Others' include undisclosed or colloquial names for which no individual plant species could be identified clearly.

However, in many cases the specific use of ash (e.g., externally as an absorbent) was not defined. Tick control by chemical dip or spray was also performed on 23% of smallholdings. Of farms that reported some form of treatment, 50.8% used only one form thereof, while 7% utilised all four treatment categories identified (Fig. 5B). The use of plants as treatments for disease was noted across both versions of the survey, with *Strychnos spinosa* the 'natal orange' the most commonly reported (Fig. 5C).

3.5. Determination of factors associated with smallholding stability and livelihoods

The interconnectivity between goat ownership and livelihoods was assessed by Fisher's exact tests with odds-ratios (OR). Here we compared responses to different survey questions to 4 main categorical factors including goat kid births (presence / absence in the last 12 months), goat deaths (presence / absence in the last 12 months), herd size (>median observed), and food insecurity (worry about sufficient food in last 7 days). Significant OR associations were found between a number of questions across the data set (S2 Table, Fig. 6). Beneficial factors of goat holdings, such as higher kid birth likelihood, were associated with reduced food worry (OR 0.33) and larger herd sizes (OR 5.83). Larger herds (as defined as >median owned) were associated with higher odds for smallholders to build savings (OR 6.58) and use goat stock for ceremonies (OR 5.65). Ownership of bucks was low but correlated with lower likelihood of food worry (OR 0.11).

Negative impacts such as goat diseases were associated with both increased likelihood of goat deaths (OR 4.84) and food worry (OR 3.48). Additionally, goat deaths were associated with decreased ability to sell stock (OR 0.18). Those with primary limitations of cash to buy more goats (i.e., not limited by diseases and predation to the same extent) were less likely to suffer from goat deaths or vice versa (OR 0.26), but those who were occupied in employment were more likely to suffer from deaths or vice versa (OR 6.57). While the directional causality of these associations was not determined, improvement in goat health and smallholding sizes appears to benefit household livelihoods.

4. Discussion

Livestock are ranked as second only to crop production in terms of importance to rural livelihoods in Malawi (Chintsanya et al., 2004; Freeman, 2008; Kaumbata et al., 2020). In this study we surveyed rural smallholders of local breed goats with similar demographics (age, farmer activities, education level, and feeding systems) to previous

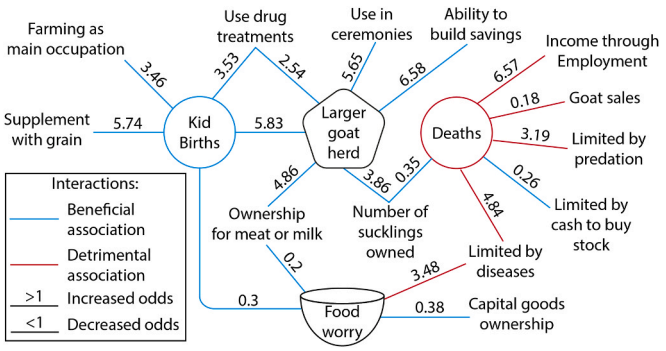

Fig. 6. Significant interactions between smallholding stability and livelihoods. Flow diagram of odds-ratio between survey responses for selected variables within the dataset (see S2 Table) with selected significant associations included (Fisher's exact test, $p < 0.05$). In each case an increase of one factor is associated with an increased odds (>1) or decreased odds (<1) of the same being true in the second factor. Main tested variables include: "kid births in the last 12 months" (presence/absence), "goat deaths in the last 12 months" (presence/absence), "food worry" (households worried about insufficient food in the past 7 days), and "goat herd size" (ownership above the median of 3 goats). Beneficial and detrimental associations are speculative assessments of the outcome for the smallholding, based on odds ratio indicating greater or lesser likelihood of better livelihood outcomes.

reports in the region (Kaumbata et al., 2020). For respondent smallholders, goats provide "help for time of need" including incurred expenses and insurance in case of emergencies, which is a common approach to improve resilience. However, present results indicate that many respondents have severe limitations to their smallholdings and their overall livelihoods. These results are compounded by climate change impacts on crop production (Jägermeyr et al., 2021) and increased risks to goat health (Cable et al., 2017), thus making it even more imperative to ensure goat survival and reproductive success to help safeguard livelihoods.

Factors surrounding successful goat management were generally associated with improved livelihoods as measured through Fisher's exact tests with OR analyses (see S2 Table, Fig. 6). For instance, those who did not suffer from recent food insecurity were more likely to have bucks in their herd (OR 9.09), improved odds of births (OR 3.33), more goat kids (OR 2.5), more capital goods (OR 2.86), more chickens (OR 3.125), and were also more likely to utilise goats for meat and/or milk (OR 5). In these cases, however, the directionality has not been determined, so it is possible that those who are better off to begin with can afford to manage more goats, including mature males (bucks), which has a knock-on positive impact on herd size and subsequently livelihoods are improved. Nevertheless, it is clear that running a successful goat smallholding has positive impacts on the livelihood of these individuals. Having enhanced livelihood security through running a successful smallholding may also signify the opportunity to consume goat meat as opposed to selling goats to buy grain, which is a strategy in food insecure households (Freeman, 2008). Alternatively, improved animal husbandry or increased attention towards promoting reproductive success of the herd (e.g., providing supplementation and ensuring effective insemination at the right time of year) could immediately positively impact the wellbeing of the household. Kid deaths make up a significant proportion of total losses, so livelihood improvement could potentially be managed through breeding at the right time of year, when goats are not nutritionally limited. Whether increased kidding improves food security warrants further investigation since householders defined "productive goats" as those with twins or triplets (90%), rather than more frequent production of single offspring. Obtaining increased litter sizes per kidding season is considered a main objective for breeding programs in Malawi, as compared to decreasing kidding interval (Nandolo et al., 2016). However, whether the former trait is more beneficial than the latter, also requires further study.

Successful husbandry practices are also linked to positive outcomes for smallholders. This can be seen as larger herd sizes (>3 goats), which were associated with offtake for ceremonies (OR 5.65), utilisation of goats for meat and/or milk (OR 4.86), and with households that could build savings (OR 6.58). We also note no discernible association between income source and ability to build savings. However, off-farm employment was associated with increased goat deaths, while farming as a main occupation was associated with increased kid births (OR 3.46) and larger herd sizes (5.83). Together, these results suggest off-farm employment to grow income may reduce goat productivity, and that properly managed full-time farming alone can yield improved livelihoods.

To identify the specifics of goat husbandry, respondents were asked to describe their management system (see Fig. 3A), based on previous descriptions in rural Malawi (Banda et al., 1993). In reaction, the majority of smallholders indicated that they allow their herd to open graze during the dry season to increase weight, but tether goats during the rainy season to prevent crop destruction. Smallholders provided a variety of feeds to tethered goats (see Fig. 3B-C), to supplement diets or – when the tethered goat could not reach graze or browse – as ration. While supplementary feeding with foliage was not directly associated with improved herd size, the use of grain was positively associated with birth success (OR 5.74). Tethering undoubtedly impacts nutrition (Caldeira et al., 2007; Muir et al., 1995) and can also potentially exacerbate exposure to, and consequent impacts from, gastrointestinal nematode parasites (Gwaze et al., 2009; Qokweni et al., 2020) as faecal contamination and parasite infection pressure accumulate and cannot be offset by avoidance behaviour (Hutchings et al., 1998). Such accumulation would depend on the re-use of the same tethering areas and goat density in the region, and persistence of herbage in tethering areas with which parasite larvae are ingested. Parasite burden can also be heightened when access to water is reduced (Ndlela et al., 2022). Impacts of goat management including tethering practices on parasite burdens, alongside nutritional factors, deserve further research attention as refinement could offer achievable low-cost opportunities for improved health.

Active goat health management was limited and may be explained by a lack of veterinary assistance and access to treatments (Gwaze et al., 2009; Monau et al., 2020), as evidenced by the restricted use of anthelmintics to treat diarrhoea, with more smallholders resorting to wood ash or medicinal plants (see Fig. 5A). With limited access to veterinary care, it is important to identify what interventions farmers utilise when goats are under performing or sick. Application of ash to the perineum of afflicted goats might reduce attraction of flies and consequent myiasis (Wall, 2012), but would not ameliorate the underlying cause of diarrhoea. Plant supplementation may however treat illnesses and a broad range of forage has been long utilised for Malawi goats but has yet to be fully described (Banda et al., 1993). We documented a diversity of potentially beneficial medicinal plants utilised by smallholders in response to goat diseases (see Fig. 5C), which offers the promise of alternative and sustainable means to supplement goat diets and provide nutraceutical benefits. For instance, the most frequently mentioned species, the Natal orange *Strychnos spinosa*, is noted to have nutritional, anthelmintic, and medicinal properties (Bullough and Leary, 1982; Mbhele et al., 2022; Waterman et al., 2010). In concert, nutritional benefits of supplementation are clearly seen in our data, with births 5.74 times more common on smallholdings using grain supplementation than in those without (S2 Table). Further study is needed, however, to identify the causative effect of supplementation and relative outcomes of specific foliage supplements. For example, sustainable utilisation of nutraceuticals (Hoste et al., 2015) such as by targeted administration (Charlier et al., 2022) could fill gaps in veterinary services, while the use of plants and other remedies also signifies farmers' awareness of diseases affecting their livestock. On the other hand, it may indicate that smallholders simply require training to rapidly identify changes in goat health, such as through the Five Point Check© (Bath and van Wyk, 2009)

to improve access to treatment options to achieve sustainable smallholdings. This effect can be seen directly, as those who managed gastrointestinal nematode disease through providing anthelmintics had a positive association with both birth success (OR 3.53) and larger herd sizes (OR 2.54). Yet, it remains to be identified what factors facilitated access to anthelmintics for these individuals.

Beyond husbandry, limitations of increasing herd size were mixed, with many reporting 'cash to buy' as a main roadblock. However, respondents limited by 'cash to buy' were >5 times less likely to have suffered from goat deaths in the previous year (OR 0.18). As such it appears that those who are not suffering from other limitations are simply limited by income to increase their herd size. No significant association was found between cash limitations and herd size, which may need further study to identify the root cause of insufficient funds for these farmers.

Future efforts to improve aspects of successful smallholdings should also consider the stochasticity of goat smallholdings over an extended period. This is necessary to separate good farming practices from catastrophes beyond the farmer's capacity to manage (e.g., predation). For instance, goat deaths occurred on 50% of smallholdings and constitute a total loss of investment with both immediate impacts, such as preventing sales, and longer-term impacts, such as collecting manure for garden crops. Those who reported deaths in the last 12 months were also 3.84 times less likely to sell any of their stock in the same period (S2 Table) and were more likely to be limited by predation (OR 3.19) and diseases (OR 4.84). The frequency of dog bites as a form of predation are also cause for concern due to the potential for rabies transmission from rabid dogs, goats, and even cattle to humans (Hampson et al., 2015), due to contact with bitten goats (Brito et al., 2011; Twabela et al., 2016).

Overall, it appears goat holdings offer a viable and effective pathway to improving livelihoods for some, but there is a real and urgent need to address limitations that prevent growth. This study identifies a number of factors which can improve livelihoods and potentially alleviate food insecurity through improvement of goat health, nutrition, and safety. Previously, breeding programs have sought to enable farmers to grow more productive goat breeds in terms of weight gain, milk yield, or reproductive rate that are achievable under non-limiting conditions (Banda et al., 1993; Kaumbata et al., 2020; Nandolo et al., 2016). However, in the face of poor nutrition, poor husbandry practices (tethering without sufficient feed rations and/or supplementation), limited reproductive success (due to lack of insemination, miscarriage, or suckling malnutrition), predation, and potentially high parasite and infectious disease pressure, the utility of exotic breeds appears limited. This is exemplified by more than double the pre-weaning mortality of Boer x Malawi goat crosses, as well as reduced weight gain of survivors of such crosses, in comparison with local Malawi breeds (Banda et al., 1993). Such limitations are also evident from shortcomings of community breeding incentives to increase production of hardy small East African local breeds in Tanzania (Nguluma et al., 2022). Rather, it appears sensible to seek means to improve the nutritional status of existing goats showing signs of disease by low-cost methods (Sargison et al., 2021; Walker et al., 2015) or at times of nutritional stress (i.e., pregnancy, weaning or tethering). Alternatively, breeding for greater tolerance or resistance to gastrointestinal nematodes and other helminths (Gwaze et al., 2009; Kosgey et al., 2006) or other biotic and abiotic stresses, would appear beneficial. In addition, providing measures to reduce predation rates and improve reproductive success can provide the capacity for sustainable offtake from their herd. Ultimately, giving farmers the capacity to offtake from their herd sustainably is the main goal for smallholders themselves, and should be the target when implementing new strategies to alleviate poverty through smallholding interventions. This can be achieved through policies aimed to educate farmers to monitor goat health (Sargison et al., 2021; Walker et al., 2015) and enable farmers to effectuate their efforts at market through cooperatives (Kaumbata et al., 2020). Lastly, the study's limitations should be considered. It is important to acknowledge that the survey was conducted exclusively within Lilongwe District. This geographical restriction was primarily due to budgetary constraints associated with expanding the research to encompass other districts. While Lilongwe District is the most densely populated and serves as a valuable focal point, it is essential to recognise that the findings may not fully represent the circumstances of more isolated, rural communities located elsewhere in the country. Furthermore, data collection involved obtaining information regarding the number of meals consumed per day by both adults and children, as well as inquiries into whether households experienced concerns about food availability in the preceding seven days. While it is acknowledged that more comprehensive measures for evaluating food security exist, the study deliberately employed non-intrusive methods for ethical considerations. This approach aimed to minimise potential discomfort or intrusion experienced by participants while still providing valuable insights. Finally, because this research adopted a cross-sectional survey design, only a static snapshot of the prevailing conditions and dynamics at the time of data collection was available. Ideally, future research encompassing other districts would facilitate the examination of longitudinal trends as they occur seasonally and socially in relation to goat health and management.

5. Conclusions

This study aimed to identify factors limiting success in goat smallholdings among rural smallholders in Lilongwe District, Malawi. Through questionnaires we assessed the relationship between goat ownership and household livelihoods, finding that maintaining goat health can have knock-on positive impacts on household livelihoods, but that a number of factors are associated with failure. While this study offers valuable insights limited to the Lilongwe District in a cross-sectional context, future research encompassing other districts would facilitate the examination of temporal trends and the exploration of potential spatio-demographic disparities. Future efforts and policies aiming to effectuate livelihood improvements through goat smallholdings should consider providing education and resources to minimise losses and maximise kidding success to the point where offtake is sustainable and self-sufficient.

Declarations

NA.

Funding information

This work was supported by the Biotechnology and Biological Sciences Research Council [grant number BB/S014748/1, 2018]. For the purpose of open access, the author has applied a Creative Commons Attribution (CC BY) license to any Author Accepted Manuscript version arising.

CRediT authorship contribution statement

PM Airs: Data curation, Formal analysis, Investigation, Methodology, Visualisation, Writing – original draft, Writing – review & editing. **J Ventura-Cordero:** Data curation, Formal analysis, Investigation, Methodology, Visualisation, Writing – original draft, Writing – review & editing. **LC Gwiriri -** Data curation, Investigation, Methodology, Writing – review & editing. **JHI Tinsley:** Writing – review & editing. **W Mvula -** Investigation, Supervision. **MRF Lee:** Funding acquisition, Writing – review & editing. **PC Nalivata** – Funding acquisition, Writing – review & editing. **J Van-Wyk:** Conceptualization, Funding acquisition, Investigation, Project administration, Supervision, Writing – review & editing. **T Takahashi**: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Writing – review & editing. **ER Morgan** – Conceptualization, Funding acquisition, Investigation, Methodology, Project administration,

Supervision, Writing – original draft, Writing – review & editing. **ACL Safalaoh** – Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare no competing interests.

Acknowledgements

The authors would like to acknowledge all survey participants and the Lilongwe University of Agriculture and Natural Resources (LUANAR), especially LUANAR members Christopher Mindozo, Victor Zilahowa, and Ian Limbe for their help in organising and liaising with survey participants translation of survey responses. This work was supported by United Kingdom Research and Innovation (UKRI) through the Global Challenges Research Fund, grant number BB/S014748/1, 2018. For the purpose of open access, the author has applied a Creative Commons Attribution (CC BY) licence to any Author Accepted Manuscript version arising.

Data Availability

Anonymized tabulated data are available in S1 File, additional anonymised survey files are available upon request.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.smallrumres.2023.107114.

References

Banda, J.W., Ayoade, J.A., Karua, S.K., Kamwanja, L.A., 1993. The local Malawi goat. World Anim. Rev. 74–75, 49–57.

Bath, G.F., van Wyk, J.A., 2009. The Five Point Check© for targeted selective treatment of internal parasites in small ruminants. Small Rumin. Res. 86, 6–13.

Bath, G.F., Penrith, M.-L., Leask, R., 2016. A questionnaire survey on diseases and problems affecting sheep and goats in communal farming regions of the Eastern Cape province, South Africa. J. S. Afr. Vet. Assoc. 87 e1–e10.

Brito, M.G., de, de Brito, M.G., Chamone, T.L., da Silva, F.J., Wada, M.Y., de Miranda, A. B., Castilho, J.G., Carrieri, M.L., Kotait, I., Lemos, F.L., 2011. Antemortem diagnosis of human rabies in a veterinarian infected when handling a herbivore in Minas Gerais. Braz. Rev. do Inst. De. Med. Trop. De. São Paulo.

Bullough, C.H., Leary, W.P., 1982. Herbal medicines used by traditional birth attendants in Malawi. Trop. Geogr. Med. 34, 81–85.

Cable, J., Barber, I., Boag, B., Ellison, A.R., Morgan, E.R., Murray, K., Pascoe, E.L., Sait, S. M., Wilson, A.J., Booth, M., 2017. Global change, parasite transmission and disease control: lessons from ecology. Philos. Trans. R. Soc. Lond. B Biol. Sci. 372.

Caldeira, R.M., Belo, A.T., Santos, C.C., Vazques, M.I., Portugal, A.V., 2007. The effect of long-term feed restriction and over-nutrition on body condition score, blood metabolites and hormonal profiles in ewes. Small Rumin. Res. 68, 242–255.

Charlier, J., Bartley, D.J., Sotiraki, S., Martinez-Valladares, M., Claerebout, E., von Samson-Himmelstjerna, G., Thamsborg, S.M., Hoste, H., Morgan, E.R., Rinaldi, L., 2022. Anthelmintic resistance in ruminants: challenges and solutions. Adv. Parasitol. 115, 171–227.

Chikagwa-Malunga, S.K., Banda, J.W., 2006. Productivity and survival ability of goats in smallholder crop/livestock farming systems in Malawi. Livest. Res. Rural Dev. 18.

Chintsanya, N.C., Chinombo, D.O., Gondwe, T.N., Wanda, G., Mwenda, A.R.E., Banda, M. C., Hami, J.C., 2004. Management of Farm Animal Genetic Resources in the Sadc Region-Malawi. Malawi Ministry of agriculture, irrigation & food security.

FAO, I.F.A.D., UNICEF, W.F.P. and WHO. 2020. The State of Food Security and Nutrition in the World 2020. Transforming food systems for affordable healthy diets. Rome, FAO.

FAOSTAT, 2022. Crops and livestock products. Rome, FAO. Available at: https://www.fao.org/faostat/en/#data/QCL [accessed 22/09/2023].

Freeman, H.A., 2008. Livestock, Livelihoods, and Vulnerability in Lesotho, Malawi, and Zambia: Designing Livestock Interventions for Emergency Situations. ILRI (aka ILCA and ILRAD).

GoM National Statistical Office, 2018. 2018 Population and Housing Census. Preliminary Report. Zomba, Malawi. Available at: https://malawi.unfpa.org/sites/default/files/resource-pdf/2018%20Census%20Preliminary%20Report.pdf [Accessed 22/09/2023].

Gwaze, F.R., Rumosa Gwaze, F., Chimonyo, M., Dzama, K., 2009. Communal goat production in Southern Africa: a review. Trop. Anim. Health Prod. 41, 1157–1168.

Haile, A., Wurzinger, M., Mueller, J., Mirkena, T., Duguma, G., Okeyo, A.M., Sölkner, J., Rischkowsky, B., 2011. Guidelines for setting up community-based sheep breeding programs in Ethiopia: Lessons and experiences for sheep breeding in low-input systems. ICARDA Tools and Guidelines 1. ICARDA,, Aleppo, Syria.

Hampson, K., Coudeville, L., Lembo, T., Sambo, M., Kieffer, A., Attlan, M., Barrat, J., Blanton, J.D., Briggs, D.J., Cleaveland, S., Costa, P., Freuling, C.M., Hiby, E., Knopf, L., Leanes, F., Meslin, F.-X., Metlin, A., Miranda, M.E., Müller, T., Nel, L.H., Recuenco, S., Rupprecht, C.E., Schumacher, C., Taylor, L., Vigilato, M.A.N., Zinsstag, J., Dushoff, J., Global Alliance for Rabies Control Partners for Rabies Prevention, 2015. Estimating the global burden of endemic canine rabies. PLoS Negl. Trop. Dis. 9, e0003709.

Hoste, H., Torres-Acosta, J.F.J., Sandoval-Castro, C.A., Mueller-Harvey, I., Sotiraki, S., Louvandini, H., Thamsborg, S.M., Terrill, T.H., 2015. Tannin containing legumes as a model for nutraceuticals against digestive parasites in livestock. Vet. Parasitol. 212, 5–17.

Hutchings, M.R., Kyriazakis, I., Anderson, D.H., Gordon, I.J., Coop, R.L., 1998. Behavioural strategies used by parasitized and non-parasitized sheep to avoid ingestion of gastro-intestinal nematodes associated with faeces. Anim. Sci. 67, 97–106.

Jägermeyr, J., Müller, C., Ruane, A.C., Elliott, J., Balkovic, J., Castillo, O., Faye, B., Foster, I., Folberth, C., Franke, J.A., Fuchs, K., Guarin, J.R., Heinke, J., Hoogenboom, G., Iizumi, T., Jain, A.K., Kelly, D., Khabarov, N., Lange, S., Lin, T.-S., Liu, W., Mialyk, O., Minoli, S., Moyer, E.J., Okada, M., Phillips, M., Porter, C., Rabin, S.S., Scheer, C., Schneider, J.M., Schyns, J.F., Skalsky, R., Smerald, A., Stella, T., Stephens, H., Webber, H., Zabel, F., Rosenzweig, C., 2021. Climate impacts on global agriculture emerge earlier in new generation of climate and crop models. Nat. Food 2, 873–885.

Kaumbata, W., Banda, L., Mészáros, G., Gondwe, T., Woodward-Greene, M.J., Rosen, B. D., Van Tassell, C.P., Sölkner, J., Wurzinger, M., 2020. Tangible and intangible benefits of local goats rearing in smallholder farms in Malawi. Small Rumin. Res. 187, 106095.

Kaumbata, W., Nakimbugwe, H., Nandolo, W., Banda, L.J., Mészáros, G., Gondwe, T., Jennifer Woodward-Greene, M., Rosen, B.D., Van Tassell, C.P., Sölkner, J., Wurzinger, M., 2021. Experiences from the Implementation of Community-Based Goat Breeding Programs in Malawi and Uganda: A Potential Approach for Conservation and Improvement of Indigenous Small Ruminants in Smallholder Farms. MDPI Sustain. 13 (3), 1494.

Kosgey, I.S., Baker, R.L., Udo, H.M.J., Van Arendonk, J.A.M., 2006. Successes and failures of small ruminant breeding programmes in the tropics: a review. Small Rumin. Res. 61, 13–28.

Mbhele, Z., Zharare, G.E., Zimudzi, C., Ntuli, N.R., 2022. Indigenous Knowledge on the Uses and Morphological Variation among Strychnos spinosa Lam. at Oyemeni Area, KwaZulu-Natal, South Africa. Sustain. Sci. Pract. Policy 14, 6623.

Monau, P., Raphaka, K., Zvinorova-Chimboza, P., Gondwe, T., 2020. Sustainable Utilization of Indigenous Goats in Southern Africa. Diversity 12, 20.

Muir, J.P., Jordao, C., Massaete, E.S., 1995. Comparative growth characteristics of goats tethered on native pasture and free-ranged on cultivated pasture. Small Rumin. Res. 17, 111–116.

Nandolo, W., Wurzinger, M., Mészáros, G., Van Tassell, C., Gondwe, T., Mulindwa, H., Sölkner, J., 2016. Identification of breeding objectives in community-based goat breeding programmes in Malawi. Acta Agric. Slov. 5, 104.

Ndlela, S.Z., Mdletshe, Z.M., Zindove, T.J., Chimonyo, M., 2022. Do water shortages increase gastrointestinal nematode loads in Nguni does? Trop. Anim. Health Prod. 54, 208.

Nguluma, A., Kyallo, M., Tarekegn, G.M., Loina, R., Nziku, Z., Chenyambuga, S., Pelle, R., 2022. Typology and characteristics of indigenous goats and production systems in different agro-ecological zones of Tanzania. Trop. Anim. Health Prod. 54, 70.

Qokweni, L., Marufu, M.C., Chimonyo, M., 2020. Attitudes and practices of resource-limited farmers on the control of gastrointestinal nematodes in goats foraging in grasslands and forestlands. Trop. Anim. Health Prod. 52, 3265–3273.

Roets, M., Kirsten, J.F., 2005. Commercialisation of goat production in South Africa. Small Rumin. Res. 60, 187–196.

Sargison, N.D., Mazeri, S., Gamble, L., Lohr, F., Chikungwa, P., Chulu, J., Hunsberger, K. T., Jourdan, N., Shah, A., Burdon Bailey, J.L., 2021. Conjunctival mucous membrane colour as an indicator for the targeted selective treatment of haemonchosis and of the general health status of peri-urban smallholder goats in southern Malawi. Prev. Vet. Med. 186, 105225.

Sidebottom, A., 2013. On the application of CRAVED to livestock theft in Malawi. Int. J. Comp. Appl. Crim. Justice 37, 195–212.

Silanikove, N., 1986. Interrelationships between feed quality, digestibility, feed consumption, and energy requirements in desert (Bedouin) and temperate (Saanen) goats. J. Dairy Sci. 69, 2157–2162.

Twabela, A.T., Mweene, A.S., Masumu, J.M., Muma, J.B., Lombe, B.P., Hankanga, C., 2016. Overview of Animal Rabies in Kinshasa Province in the Democratic Republic of Congo. PLoS One 11, e0150403.

Walker, J.G., Ofithile, M., Tavolaro, F.M., van Wyk, J.A., Evans, K., Morgan, E.R., 2015. Mixed methods evaluation of targeted selective anthelmintic treatment by resource-poor smallholder goat farmers in Botswana. Vet. Parasitol. 214, 80–88.

Wall, R., 2012. Ovine cutaneous myiasis: effects on production and control. Vet. Parasitol. 189, 44–51.

Waterman, C., Smith, R.A., Pontiggia, L., DerMarderosian, A., 2010. Anthelmintic screening of Sub-Saharan African plants used in traditional medicine. J. Ethnopharmacol. 127, 755–759.