Small Ruminant Research 255 (2026) 107678

Contents lists available at ScienceDirect

Small Ruminant Research

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

Five Point Check©-based management of goat health can be self-sustainable without long-term public funding: A 5-year retrospective study of Malawi smallholdings

Paul M. Airs [a,b,*], Jonathan H.I. Tinsley [b], Winchester Mvula [c], Taro Takahashi [d,e], Jan A. van Wyk [f], Eric R. Morgan [b], Andrews Safalaoh [c]

[a] Murray Edwards College, University of Cambridge, Cambridge, UK
[b] Institute for Global Food Security, Queen's University Belfast, Belfast, Northern Ireland, UK
[c] Animal Science Department, Lilongwe University of Agriculture and Natural Resources (LUANAR), Lilongwe, Malawi
[d] Agri-Food and Biosciences Institute, Hillsborough, Co. Down, Northern Ireland, UK
[e] Bristol Veterinary School, University of Bristol, Bristol, UK
[f] Department of Veterinary Tropical Diseases, University of Pretoria, Pretoria, South Africa

ARTICLE INFO

Keywords:
Low-resource
Botanical natural resources
Gastrointestinal nematode
Nutrition
Animal disease
Climate change adaptation

ABSTRACT

Failure to manage goat nutrition or control gastrointestinal nematode parasites (GINs) can lead to low performance and livestock losses on smallholdings. Programs to improve smallholder goat health can have an immediate positive impact but often depend on external expertise and resources such as anthelmintic interventions. As a result, programs may fail to support smallholders once external resources, such as grant funding, are removed. With this in mind, a low-resource targeted-selective treatment (TST) program based on a hands-on Five Point Check© (FPC) scoring system was undertaken from 2020 to 2021 in rural Central Malawi. Participating smallholders were educated and equipped to perform goat health scoring and provide interventions on an as needed basis. In April 2025, five years after the study began, original participants were surveyed alongside control non-participants to determine the impact, uptake, and dissemination of TST using the FPC. 97.5 % of participants remembered the FPC and 73.8–92.9 % still used FPC tests on their goats. Practicing the FPC increased farmers' confidence and success and decreased the likelihood of being impacted by disease or ill health. As a result of the FPC, targeted beneficial plant supplementation and anthelmintic use to treat sick goats was maintained among study participants. Non-study controls were unanimously in favour of using the FPC, but gaps exist in supporting dissemination of training and materials (such as FAMACHA cards and anthelmintic) to the wider smallholder community. Overall, this study shows that education and sustainable practices can be adopted and self-sustained in low-resource areas following initial investment.

1. Introduction

Goats are an intrinsic part of rural livelihoods among subsistence farmers and rural populations worldwide. In Malawi, goats are the most common livestock kept besides chickens, with 11.1 million goats in 2021, up from 4.2 million in 2011 (Food and Agriculture Organisation (FAO), 2022). Goat smallholdings make up 20 % of all households in Malawi, and up to 90 % of rural households (FAO, 2022; Freeman, 2008). Smallholdings play a number of roles with economic, cultural, and other intangible benefits, but principally act as security to cover household expenses such as school fees, agricultural supplies, or emergencies (Airs et al., 2023a; Kaumbata et al., 2020; Rumosa Gwaze et al., 2009). In difficult circumstances, goats can also be sold via informal market chains to local butchers in order to offset food insecurity, especially after crop failure (Maganga et al., 2015). As a result, the health and success of goat smallholdings is directly linked to food security (Airs et al., 2023a). Malawi being particularly vulnerable with half the population at risk of severe food insecurity (FAO, 2025).

Effective goat management is therefore critical to ensuring the poverty alleviation and resilience benefits of smallholdings. In Malawi however, goat management is strongly constrained by agricultural activity and other rural occupations, with goats tethered or housed during

* Correspondence to: Queen's University Belfast.
E-mail address: p.airs@qub.ac.uk (P.M. Airs).

https://doi.org/10.1016/j.smallrumres.2025.107678
Received 9 September 2025; Received in revised form 28 November 2025; Accepted 3 December 2025
Available online 4 December 2025

the day and through the growing season (Airs et al., 2023a; Banda et al., 1993). Tethering puts goats at risk of malnutrition, but this practice can support good goat health when provided with sufficient nutrients and care (Romney et al., 1996). Restricting goat movement also exposes goats to gastrointestinal nematode parasites (GINs) while minimising the ability of goats to selectively browse (Qokweni et al., 2020). Because of this, tethering practices can result in rapid deterioration and death if GIN infections are not controlled (Besier et al., 2016; Caldeira et al., 2007; Hoste et al., 2005; Muir et al., 1995). Of particular concern are pathogenic species such as *Haemonchus contortus* and *Trichostrongylus colubriformis*, which are highly pathogenic and predominate GIN populations on Malawi smallholdings (Airs et al., 2023b; Sargison et al., 2021). Monitoring goat health typically requires laboratory diagnostic tools, e.g., faecal egg counts (FECs), or indirect measurements of performance metrics such as live weight gain (Githigia et al., 2001; Kaplan et al., 2023; Learmount et al., 2016; Sabatini et al., 2023).

In rural areas, hands on, no-cost approaches to assess for GINs and track performance have been developed such as body condition scoring (BCS) and the FAMACHA assessment of anaemia (Honhold et al., 1989; Olah et al., 2015; Sabatini et al., 2023; van Wyk and Bath, 2002). BCS inspections of the lumbar area effectively estimate fat or muscle deposits in sheep or goats respectively, which are critical markers of health and performance (Honhold et al., 1989; Kenyon et al., 2014; Villaquiran et al., 2004). FAMACHA scoring is similarly effective at monitoring anaemia and the impact of *H. contortus* infections in rural smallholder settings (Mahieu et al., 2007; Sargison et al., 2021; van Wyk and Bath, 2002).

The Five Point Check© (FPC) goes further and incorporates FAMACHA and BCS along with other signs of disease including bottle jaw (pitting edema), nasal discharge, and dag (scour) (Bath and van Wyk, 2009). With proper training, the FPC is a reliable means to detect the presence and impacts of GIN disease, and other common ailments, in remote settings (Bath and van Wyk, 2009; Walker et al., 2015). This system is especially amenable to low-resource settings since the only 'equipment' necessary to carry out the FPC is the FAMACHA card, a small laminated card by which to estimate anaemia via colouration of conjunctival mucous membranes (Bath and van Wyk, 2009; van Wyk and Bath, 2002)

Since the FPC system is a quantitative assessment, it can be a framework for Targeted Selective Treatment (TST) whereby interventions, such as anthelmintics or dietary supplementation, are directed to specific individuals at specific moments in time (Bath and van Wyk, 2009; Besier, 2012; Charlier et al., 2014; Kenyon et al., 2009). By using individual thresholds, TST drastically reduces the need for *ex post* interventions and hence reduces costs compared to group or herd level treatments, since the majority of individuals do not require interventions for the majority of the time (Bath and van Wyk, 2009; van Wyk et al., 2006). TST has the added benefit of making anthelmintics more affordable and accessible to low-resource smallholders due to the lower overall dosage. Furthermore, the emergence of anthelmintic resistance, (which is widespread globally and a documented problem in goats in Africa (Guinda et al., 2025; Mavundela et al., 2025)), is attenuated by TST, which preserves susceptible parasite genotypes for later mixing with resistant survivors of treatment (Bath and van Wyk, 2009; van Wyk, 2001).

To support the management of goat production and sustainably control GINs with minimal inputs and to make anthelmintic use more affordable and accessible, we trialled a FPC based TST program in rural Malawi from January 2020-March 2021 (Ventura-Cordero et al., 2025). During the project we provided training to perform the FPC and TST, delivered via public funding. Through monitoring of individual goat health scores, the TST regimes reduced goat deaths while using substantially less anthelmintic compared to whole-herd treatments. However, exclusive reliance on anthelmintics for helminth management still makes this approach useless for individuals who simply cannot access or afford these interventions. In order to overcome this barrier, a subset of TST farmers were also provided targeted-selective botanical supplementation (Plant-TST), whereby locally available beneficial plants were used to limit the impacts of GINs and malnutrition of smallholder goats and further offset the need for anthelmintic interventions (Ventura-Cordero et al., 2025). Use of Plant-TST reduced anthelmintic need by a further 54 % compared to TST alone, with anthelmintic provided following just 2 % of FPC tests.

While the trial was successful, determining the long term impacts or legacy of public programs is often not performed due to the periodic nature of funding (Wiltsey Stirman et al., 2012). Whether a FPC based TST approach can be adopted in a self-sufficient manner by rural farmers after external support has been withdrawn has not been extensively surveyed. To this end, a 5 year retrospective survey was performed among participants of the 2020 TST study (Ventura-Cordero et al., 2025), alongside non-participant control farmers. The present survey aimed to determine whether the 2020 TST study had any lasting impacts on sustainable goat production and if farmers disseminated knowledge of these practices to other farmers in the local area. Crucially, the study was aimed at determining whether farmers had the capacity to continue performing the FPC and TST in the absence of outside support and prompting.

2. Materials and methods

2.1. Study area and timeline

Central Malawi's Lilongwe District is an area with a wet tropical climate with conditions representative of the wider region. The Lilongwe district was chosen for the initial TST-study due to the considerable goat ownership in this region as well as the gross overall population with 1.64 million inhabitants in 2018 (GoM National Statistical Office, 2018). Initially, a 2019 pre-study survey of goat management practices and socioeconomics was carried out in the region (see Airs et al., 2023a). This was followed by the TST-study as described separately (see Ventura-Cordero et al., 2025) and the current retrospective survey (Fig. 1a).

For the retrospective analysis presented here, the study area includes the TST-study area villages (Mkwinda, Kamchezera, Mazinga, and Chikhowe villages) as well as several control villages (Bauleni and Kanyumbu)(Fig. 1b).

2.2. Survey design, data collection, and study groups

A quantitative survey was designed as part of a larger project among smallholders in Malawi relating to goat management, natural resource use, and goat health. Questions were targeted towards opinions, knowledge, and use of the FPC and use of botanical natural resources. Blank copies of the survey and consent form are available at: https://github.com/PaulAirs/Malawi_Botanical_Natural_Resources_Goat.

Basic household characteristics data, mainly demographic, socioeconomic, and goat management information were based on a pre-study survey performed prior to the TST study in 2019, carried out in the same area as the study (Airs et al., 2023a). A subset of questions, numbers 17–28, relating to botanical resource use have been reserved for publication separately.

Survey responses were collected from April 17–30 2025 by a team of trained researchers from the Lilongwe University of Agriculture and Natural Resources (LUANAR). All surveys were performed by informed consent according to the ethical review (see ethics declaration). The identical methodology for respondent information collection was used in both the pre-study survey in 2019 and the present (retrospective) study.

The survey was targeted towards participant farmers from the initial 2020 TST-study ($n = 42$) including both TST ($n = 20$) and Plant-TST ($n = 22$) groups allocated to different villages (Fig. 1b). A non-study control group ($n = 90$) of individual goat smallholders who were not

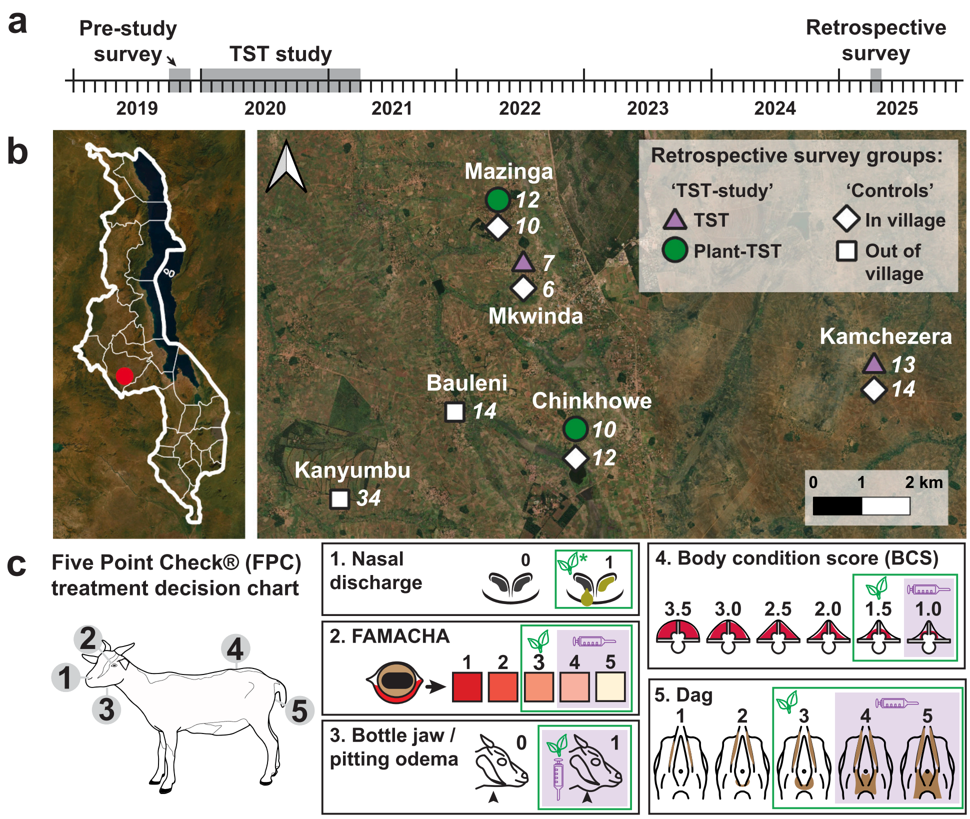

Fig. 1. Targeted Selective Treatment (TST) study design. (a) Timeline showing farmer visitation dates for a 2019 pre-study survey (see Airs et al., 2023a), the TST-study (see Ventura-Cordero et al., 2025), and the current retrospective survey. (b) Map of Malawi on the left showing the gross study area (red circle) and a local area map on the right. Responses for the retrospective survey were collected from goat farmers who took part in the initial 2020 study as well as a control group of goat farmers who were never part of the initial study. Numbers indicate the total respondents to the 2025 survey from each group and location. (c) The Five Point Check® (FPC) treatment decision chart used for the TST-study. For both TST and Plant-TST groups, individual sick goats were provided anthelmintic based on nasal discharge (goat image, point 1) FAMACHA (2), bottle jaw (3), body condition score (BCS, 4), or dag scores (5) (purple boxes). For Plant-TST, locally available beneficial plants were additionally provided based on poor or intermediate health scores (green boxes).

part of the initial 2020 study but lived in the same area (both inside and outside the TST/Plant-TST villages) was also collected, herein referred to collectively as "Controls" (Fig. 1b). Control responses were gathered to benchmark the impact of TST on sustainable goat production and to determine spontaneous uptake and undirected dissemination of TST practices among the local population. The control group includes 'Control-Plant-TST' ($n = 22$) and 'Control-TST' ($n = 20$) farmers who live within the study area villages, as well as 'out of village' area control farmers ($n = 48$)(Fig. 1b).

2.3. Targeted selective treatment using the Five Point Check

The original study was performed from January 2020 to March 2021 in Mkwinda, Kamchezera, Mazinga, and Chikhowe villages, whereby participating farmers were trained and instructed to perform TST using the FPC as described previously (Ventura-Cordero et al., 2025). In this study, the FPC was performed by farmers under observation from researchers and/or veterinary assistants approximately every 14-days for the study duration. Two groups carrying out TST were formed across four villages (Fig. 1a-b). In all four villages, study participants performed 'TST' and treated sick individual goats with anthelmintic (albendazole, Albendex 100, Alfavet®, Kenya, administered at a dose of 10 mg/kg of body weight as estimated by weigh tape). Treatments were performed by, or under the supervision of the research team and/or a local veterinary assistant. In two villages, a subgroup of participants formed the Plant-TST group, who performed TST with anthelmintic treatment as above, but also supplemented goats in a 'borderline' or 'sick' condition as determined by a treatment decision chart (Fig. 1b). Botanical supplementations were provided using ~ 250 g of fresh harvested locally available beneficial plants once a day for 5 days following the FPC (Ventura-Cordero et al., 2025). Beneficial plants included *Commiphora africana* (A. Rich) Engl. (common name = Kakhobo or African Myrrh), *Ficus ingens* Miq (Mtawa), or *Gmelina arborea* Roxb (Malayina) and were selected based on their availability, prior use, non-toxicity, nutrient profiles, and potential nutraceutical impacts.

Following the termination of the study, farmers were free to continue this practice as they saw fit with their local veterinary assistants. For smallholders to gain access to anthelmintics as needed in the absence of the research team, veterinary assistants and representative farmers in the study area were provided with drug boxes. Individuals with boxes had been provided training to perform the FPC and administer TST based on the treatment decision chart during the study. Every box was stocked with 1 litre of albendazole (Albendex 100, Alfavet®, Kenya), to be administered at a dose of 10 mg/kg of body weight administered orally, along with syringes for administration. Each TST village chose a committee to manage the drug box. After the study ended, drug boxes were passed into the full control of local people with the goal of generating funds to replenish drugs and materials in a self-sufficient manner. Due to the project ending in 2021 there is limited detail available relating to payments and use.

In 2025, retrospective survey responses were gained from original participants from the TST-study as well as in village and out of village control farmers (Fig. 1). Participants for the 2025 retrospective survey were screened based on prior-participation, goat ownership, and management.

While researchers provided training and assistance through the study period, participating farmers were also trained and provided with skills and materials necessary to perform the FPC on their own, including a FAMACHA card (Bath and van Wyk, 2009). Plant-TST participating farmers also received containers to estimate quantities of botanical resources for Plant-TST and were free to utilise local knowledge of beneficial plant species to provide interventions *in lieu* of anthelmintic when necessary.

In order to assess the adoption of the TST and Plant-TST among study participants without external influence, no contact was made between participating farmers and researchers following the study's end in March 2021 until the 2025 survey collection (April 17th - 30th).

2.4. Statistical analysis and graphical outputs

Data was formatted in Microsoft Excel and anonymised (available here: https://github.com/PaulAirs/Malawi_Botanical_Natural_Resources_Goat). Map data were generated in QGIS (version 3.40.5-Bratislava, QGIS.org) using generalised GPS coordinates of survey collection villages. Illustrations and figures were formatted in Adobe Illustrator (version 29.6, Adobe Inc. 2025).

Analyses and graphical figure outputs were performed in R version 4.5.1 (2025–06–13) – "Great Square Root" (Core Team, 2020). Pearson's Chi-squared tests with Yates' continuity correction were performed for contingency analyses. Two-sided Fisher's Exact Tests for count data with simulated p-value (based on 10000 replicates) used in cases of low counts data in the contingency table and for odds ratio analyses.

To identify the strongest associations across logical, categorical, and numerical survey variables, pairwise correlations were performed across a condensed version of the dataset (S1 File). "Yes" and "sometimes" responses were categorised as TRUE, while "no" was recorded as FALSE. Categorical data was included as unordered factors with 2–9 levels. Factor variables with > 10 unique levels were excluded to minimise instability in contingency tables and reduce the likelihood of spurious associations. Further, question 2 "What livestock did you own in the last year and which are the most important to you?" was collapsed into total livestock owned (minus chickens) and a count of total different livestock owned. Similarly question 6 "How many of these capital goods do you own? (number for each)" was collapsed into total items owned and a count of total different items owned. For question 10 "How many goats did you own or gain in the last 12 months?" the total number owned, purchased/traded, and that died were combined. Categorical–categorical relationships were quantified using Cramér's V, with p-values estimated via Fisher's exact test. Numeric-numeric comparisons as well as categorical-numeric comparisons were assessed using the point-biserial correlation coefficient, calculated via Pearson's product-moment method. Results were thresholded with a p-value of < 0.05 for variables with > 10 non-missing observations. Finally, to assess the potentially confounding influence of individual villages on the treatment effect, mixed-effects logistic regressions (based on generalized linear mixed models) were performed for all cases where the binary impact in question concerns goat health or associated management outcomes. Individual villages were included in the model as either a fixed effect or a random effect depending on the specification (S2 File).

3. Results

3.1. Demographics and livelihoods

Respondents demographics were representative of households in the area based on a 2019 pre-study survey (Airs et al., 2023a). There were slightly more female than male respondents for both TST-study and Controls ($\chi^2 = 1.1947$, df $= 1$, p $= 0.2744$) (Figure S1a), representative of smallholding livestock ownership in Malawi (FAO, 2022). Respondent age also skewed towards those over 60 for both groups ($\chi^2 = 2.2$, df $= 4$, p $= 0.6973$) but a range of age groups were captured (Figure S1b).

For occupation, most respondents were farmers or farmers/entrepreneurs (85.36 % TST-study vs 77.77 % Controls, Fisher's Exact Test, p $= 0.16$) (Figure S1c). This distribution was similar to the pre-study survey (84 % farmers, 2019) (Airs et al., 2023a). Education was similarly distributed among TST-study and Control responses (Fisher's Exact Test, p $= 0.6186$). In both response groups ~60 % of respondents have a primary level education with ~15 % having no formal education (Figure S1d). Education is also in line with the 2019 pre-study survey (60 % with primary schooling, 20 % with no formal education).

Livelihood indicators included: food worry, household meals per day, flock size limitation by cash, capital goods ownership, and livestock ownership. There were no significant differences in livelihoods between the TST-study and Controls (S1 File). Capital goods ownership was stable over time (2019 vs 2025 survey responses) and between groups (TST-study vs Controls) (Figure S2a, Tables S1-2). Food insecurity was estimated through asking "in the past 7 days, did you worry that your household would not have enough food?" (Table S3). This question was asked during the 2019 pre-study survey in the same area (Airs et al., 2023a). Food worry was related mildly to income source, with farmers and entrepreneurs less likely to suffer from food worry compared to those not working (Figure S2b). No significant change was found for those reporting food worry either between 2019 (41 %) and 2025 (33 %) surveys, or between TST-study participants (39 %) and Controls (31 %) (Multiple χ^2 with p-values > 0.1). A similar trend was seen for the number of meals taken per day for adults (median $= 2$) and separately for children (median $= 3$) (Table S4 and S5). Approximately half of participants in both groups also stated that they are better off now compared to 2019 (Table S6). Overall, there were several significant relationships between different livelihood indicators, indicating that survey responses are not random, and that socio-economic status varies within the dataset (Figure S2c).

3.2. Uptake of the FPC among goat smallholders in the study area

Following the end of the TST study in March 2021, participating farmers were left to continue using TST *ad libitum*. Given that performing TST using the FPC only requires a FAMACHA card (which were provided to all participating farmers) and the ability to remember or record goat health scores over time, participating farmers were assumed capable of performing TST on their own. Use of the FPC for TST however depends on whether farmers retain the ability to perform tests and see their usefulness.

To assess uptake and dissemination of the FPC, respondents were asked about their knowledge and opinions of the FPC (Table 1). Awareness of the FPC was largely retained by study participants (97.6 % remembering the FPC) who did not disseminate knowledge widely (6.9 % awareness among Controls) (Table 1 Part A). However, responses were unanimously in favour of using the FPC across both groups if provided with training and materials.

To test knowledge of the FPC, individual farmers were asked to describe if they 'know how to perform' each of the FPC steps. Study participants retained the ability to demonstrate all steps of the FPC except one individual in the TST group who could only perform FAMACHA, and five other instances where individuals did not perform the nasal discharge examination. Despite a low overall knowledge of the FPC among Controls, over half were able to demonstrate dag and BCS examinations while a smaller number could perform nasal discharge, bottle jaw, and FAMACHA examinations.

Next, participants were asked which aspects of the FPC were still being used. Overall, 57 % of TST-study participants used all 5 of the FPC tests while a further 21 % used 4/5 tests. Responses were significantly different between study participants and Controls for each part of the FPC (Table 1 Part C).

Participants were also asked if the FPC was considered useful. Study participants were more likely to find FAMACHA useful, possibly owing to their knowledge and experience with this test (Table 1 Part D). TST-study participants and Controls did not differ in options of nasal

Table 1
Five Point Check uptake and dissemination between TST-study and Control farmers.

	TST-study groups		Control groups			
Answers:	Yes	No / don't know	Yes	No / don't know	χ^2	p-value
Part A - FPC related questions:						
Knows of the FPC	40	1	0	81	95.6	< 0.001
Would use the FPC if provided materials and training	41	0	90	0	0.0	1.000
Part B - Know how to perform the FPC tests:						
FAMACHA	41	0	4	70	95.2	< 0.001
Bottle jaw	40	1	11	63	69.8	< 0.001
Nasal discharge	35	6	11	63	51.7	< 0.001
BCS	40	1	48	26	13.9	< 0.001
Dag	40	1	59	15	5.6	0.018
Part C - Uses the FPC tests on their goats:						
FAMACHA	29	12	1	73	62.3	< 0.001
Bottle jaw	36	5	11	63	55.1	< 0.001
Nasal discharge	31	10	12	62	37.3	< 0.001
BCS	36	5	45	29	8.0	0.005
Dag	39	2	52	22	8.4	0.004
Part D - 'Think the FPC tests are useful':						
FAMACHA	41	0	41	33	23.5	< 0.001
Bottle jaw	32	9	47	27	2.0	0.162
Nasal discharge	30	11	43	31	2.0	0.160
BCS	33	8	51	23	1.3	0.263
Dag	32	9	56	21	0.2	0.682
Part E - FAMACHA related questions:						
Know what a FAMACHA card is	41	1	1	86	115.7	< 0.001
Own a FAMACHA card	37	5	0	89	105.0	< 0.001
Used a FAMACHA card	33	9	0	86	87.0	< 0.001
Know someone with a FAMACHA card who can help	39	3	3	86	100.8	< 0.001
Currently use a FAMACHA card, or keep using one in the future?	40	0	72	16	6.7	0.009

discharge, bottle jaw, BCS, or dag.

Overall, there was a high level of overlap between TST-study farmers' knowledge, use, and opinion of FPC usefulness (Fig. 2). For TST-study participants, almost all individuals responded 'yes' to all three of these questions, while this was only true for BCS and Dag in the Controls group. For FAMACHA, bottle jaw, and nasal discharge, many Control respondents who were not part of the TST-study thought these tests would be useful, although the majority lacked knowledge of these tests (see Table 1 Part A).

3.2.1. *Future use and utility of the FPC*

TST-study farmers were asked an open-ended question about why they would continue to perform the FPC in the future. Responses varied but centred around the ability to track goat health and diagnose diseases (85.7 %) (Table S7). Productivity, management, and profitability (35.7 %) were also mentioned as reasons less frequently. Some farmers gave multiple reasons, with one farmer stating the FPC helped with "early detection of sick goats, improve health of goats, resulting in more profit".

At the end of the survey, all participants were asked if they agreed with four statements about the FPC (Table 2). Statements relating to health generated the strongest positive responses from respondents. By this point in the survey, non-study Controls had learned about the FPC but had not received formal training. Comparing TST-study and Controls, significantly more of those with experience of the FPC agreed with each statement. Most significantly, 40 % of TST-study participants say they use less resources than before (vs 3 % of Controls), and 45 % are more confident in keeping goats (vs 2 % of Controls).

3.2.2. *FAMACHA card ownership and use among goat smallholders*

Carrying out the FPC requires use of a FAMACHA card, a small, laminated card that helps operators to estimate the degree of anaemia. The card carries colour photographs of each degree of anaemia to match with the goat being inspected, and this standardisation enables accurate scoring of haemonchosis (Bath and van Wyk, 2009; van Wyk and Bath, 2002). Therefore, access to the FAMACHA card and training in its use is a limiting factor preventing non-study farmers from carrying out the FPC properly. To probe further into the continued use of this test, respondents were asked further questions relating to FAMACHA cards (Table 1 Part E). As expected, non-study participants (Controls) almost universally did not own or use FAMACHA cards, but 82 % said they would use one in the future. Almost all TST-study farmers said they knew what a FAMACHA card was (41/42), owned a FAMACHA card (37/42), knew someone who owned a FAMACHA card who could help them (39/42), and/or would use a FAMACHA card in the future (40/40). Of the 6 TST-participants who said they did not own a FAMACHA card, 3 said they knew someone with one. The majority of TST-study participants also said they used their FAMACHA cards (33 yes, 9 no).

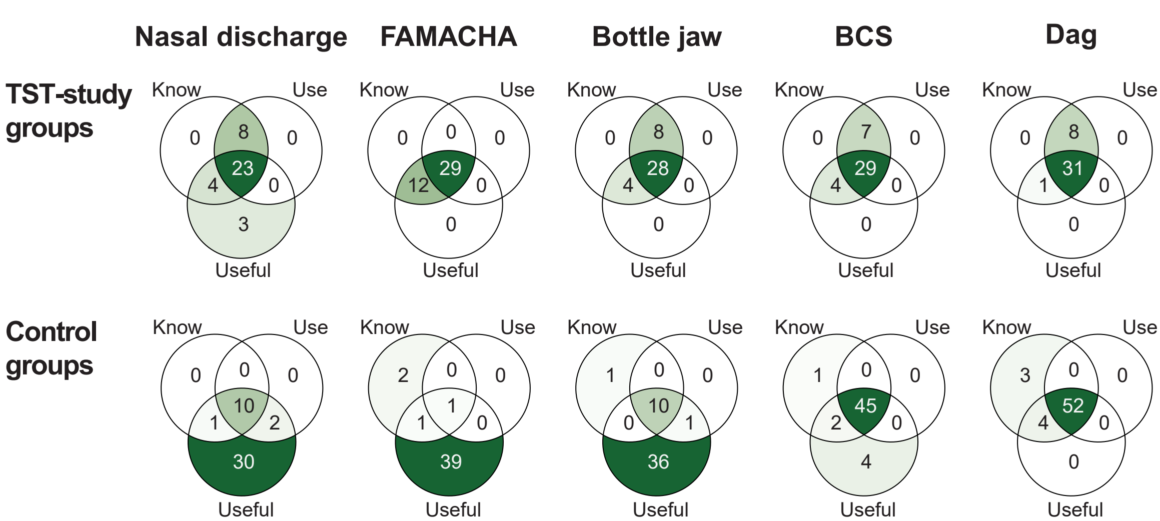

Fig. 2. Use and opinions of the Five Point Check among study area goat farmers. Venn diagrams showing the occurrences of respondents who (Know) "Know how to perform this test", (Use) "Use this check on my goats", and (Useful) "Think this check is useful". Those who answered 'no' to all of these questions or did not answer were excluded. TST-study (n = 42) and Control (n = 90) groups were pooled across all relevant villages.

Table 2
Question "Do you agree with any of these statements about using the Five Point Check?".

Checkbox	Plant-TST group†	TST group†	TST-study groups†	Control groups†	χ^2*	df*	p-value*
More confident keeping goats	11 (50)	8 (40)	19 (45)	2 (2)	27.909	1	< 0.0001
More successful keeping my goats healthy	19 (86)	16 (80)	35 (83)	47 (52)	10.494	1	0.0012
Better tell when my goats are sick	21 (95)	18 (90)	39 (93)	62 (69)	7.8697	1	0.005
Use less resources than before	10 (45)	7 (35)	17 (40)	3 (3)	36.458	1	< 0.0001

† Number of responses with (%) of responses in brackets.
* Pearson's Chi-squared test with Yates' continuity correction for 'yes' vs 'no/blanks' for TST-study vs Controls counts.

3.3. Dissemination of knowledge

Knowledge and awareness of the FPC among non-study controls was low, so it can be assumed that the FPC was not widely disseminated between study and non-study farmers (Table 1 Part A-D). During the TST-study, participant farmers were not given any instructions relating to knowledge sharing, so there is no assumption of knowledge sharing between farmers. However, when asked "do farmers share knowledge about how to keep goats healthy?", significantly more TST-study farmers reported to share knowledge compared to Controls (78.6 % of TST-study participants vs 51.8 % of Controls, $\chi^2 = 7.37$, df = 1, p = 0.0066, Table S8). Sharing knowledge did not differ between Plant-TST and TST groups ($\chi^2 = 0.026033$, df = 1, p = 0.87). There were also no differences between Control respondents within the study area vs outside ($\chi^2 = 0.92026$, df = 1, p = 0.3374). The results of the mixed-effects logistic regressions suggested that some treatment effects become weaker once the individual village effect is accounted for, likely meaning that both location and involvement in the TST study influenced knowledge sharing to a certain degree (S2 File).

To assess the wider knowledge around the FPC, respondents were also asked "have you heard about worm parasites that affect goats?" to which most said they had (85.6 %), but awareness was higher among TST-study participants (41/42 TST-study vs 72/87 Controls, $\chi^2 = 4.47$, df = 1, p = 0.0344). Awareness of parasites was also correlated to knowledge sharing (Cramer's V = 0.35, p < 0.001), access to veterinary care (Cramer's V = 0.33, p < 0.001), and access to anthelmintics (Cramer's V = 0.37, p = <0.0001) (S1 File).

In terms of sharing botanical knowledge, both the Plant-TST (68 %) and TST (60 %) groups said they learned about botanical supplementation for sick goats through training (including from the TST-study), compared to just 4 % of Controls (Table S9). Personal experience and indigenous knowledge were also listed as sources, and a small number ($n = 10$, 7.5 %) indicated that other farmers or TST-study participants had taught them about the use of botanical natural resources to improve goat health.

3.4. Feed management and uptake of Plant-TST supplementation

Use of local botanical resources is a common means of nourishing goats, especially when they are tethered during the crop growing season (Airs et al., 2023a; Banda et al., 1993). 100 % of survey respondents stated that they harvest from local trees to supplement their goats' diet, with feed management practice similar across seasons between TST-study participants and Controls (Table S10). Strategies involved free-grazing and herding in communal 'dambo' pastureland as well as on crop residue in fields during the dry season, switching to cut and carry forage during the growing (rainy) season (Table S10) (Airs et al., 2023a).

When asked if "additional food" is provided to sick or struggling goats, the majority of responses were 'yes' or 'sometimes' (Table S11). During the TST-study, the Plant-TST group was instructed to provide a set amount of *C. africana*, *F. ingens*, or *G. arborea* to borderline or sick individual goats (see Fig. 1b and Section 2.3). Harvesting of each of these plants to supplement goats was maintained by the majority of Plant-TST participants (Table S11). Use of these plants was also significantly higher among Plant-TST participants vs Controls and did not differ for the TST group vs Controls (Table 3). Looking at village effects under mixed-effects models, Chinkhowe (a Plant-TST village) had significantly more respondents using *C. africana* or *G. arborea* compared to Kanyumbu, Mkwinda, and Kamchezera villages, but not compared to Mazinga (the other Plant-TST village) (S2 File). However, Mkwinda (a TST village) was also more likely to use *C. africana* than Kanyumbu. Combined together, while the increased use of these plants may in part be a result of the initial Plant-TST intervention, it is likely also dictated by local plant availability.

Beneficial plant use correlated to those who "use less resources than before" for *C. africana* (Cramer's V = 0.31, p < 0.001), *G. arborea* (Cramer's V = 0.19, p < 0.04), and *F. ingens* (Cramer's V = 0.41, p < 0.001) (S1 File). Plant use was also evident among TST-study participants, who were more likely to use cut and carry forage (likely including beneficial plants) to feed their goats during the dry season compared to Controls ($\chi^2 = 10.547$, df = 1, p = 0.001). TST-study participants were also more likely to be limited by feed availability compared to Controls (Table S12, Table S13).

3.5. Impact of TST on smallholdings

3.5.1. Gains, losses, and size of goat holdings

The TST-study had several impacts on holdings and may have indirectly benefitted livelihoods. As a baseline, larger goat holdings were correlated to those with more resources (see Figure S2c). Since both TST-study and Control groups are similarly distributed across livelihood factors, both groups were assumed equal across holding factors. However, TST-study goat holdings were larger on average (Table S12, median = 7 for TST-study vs 5 for Controls). TST-study smallholdings were also more likely to utilise their goats for food or to sell goats at market (Table S12, $\chi^2 = 4.24$, df = 1, p = 0.04). Further, goat losses due to theft, deaths, and predation were not significantly different between TST-study and Control groups ($\chi^2 = 1.59$, df = 1, p = 0.21). Narrowing in on goat deaths due to predation or unknown causes also showed no significant differences between the TST-study and Controls ($\chi^2 = 3.41$, df = 1, p = 0.065). While not significant, more individuals in the TST-study group experienced losses compared to Controls (71.8 % vs 59.3 %), possibly owing to the increase in holding size. The lack of monitoring during this period however minimised the scope for

Table 3
Odds ratios for use of Plant-TST beneficial species as supplements for sick goats*.

Test**	*Commiphora africana*	*Ficus ingens*	*Gmelina arborea*
Plant-TST vs TST	**6 (0.011)**	3.1 (0.12)	**13.6 (<0.001)**
Plant-TST vs Controls	**13.9 (<0.001)**	**5.2 (0.001)**	**7.8 (<0.001)**
TST vs Controls	2.3 (0.14)	1.6 (0.42)	0.53 (0.318)

* See Table S11 for count data.
** Two-sided Fisher's Exact Test performed in 2 × 2 contingencies for each occurrence. Shows odds ratios with p values in parentheses. Significant results in **bold**.

determining causes of death due to parasites and other diseases as opposed to predation and other extraneous factors.

Differences between holdings were also seen at the village level between Plant-TST, TST, and respective in-village control groups (Table S12b). Both Plant-TST and TST groups had larger holdings and higher rates of goats being used by smallholders than their respective in-village controls (Table S12b). The Plant-TST group showed the overall highest proportion and median number of goats sold, while the TST group had the highest median holding size. However, both Plant-TST and TST groups also suffered from more losses compared to their in-village controls, signalling that the success of achieving larger holdings also resulted in more risk.

3.5.2. Farming limitations

Smallholders in both TST-study and Control groups were limited by a number of factors, with all smallholders wanting to increase their flock (100 % of respondents). The majority of all respondents were limited by cash, dog bites, and theft of livestock (Table S13). There were no significant differences in the presence/absence of these limitations between individual villages (S2 File). Between groups, Plant-TST smallholders reported a decreased likelihood of being "limited by health" or "limited by disease" when compared to the TST group or Controls (Table S13). This is in line with TST-participants citing the health benefits of using the FPC (Table S7). Further, 'feed' was more likely to be a limitation for Plant-TST and TST group farmers compared to Controls, possibly indicating the decreased pressure from disease.

Respondents who were "limited by disease" (Pearson's $r = 0.194$, $p = 0.026$), "limited by health" (Pearson's $r = 0.23$, $p = 0.009$), or "limited by dog bites" (Pearson's $r = 0.22$, $p = 0.014$) were all associated with increased goat deaths (S1 File). Those who experienced goat deaths also had a higher chance of food worry (Cramer's $V = 0.36$, $p = 0.014$). Therefore, the TST-study may have indirectly benefitted livelihoods though reducing disease pressure. Taken together with holding results in Section 3.5.1., it appears that TST-study farmers were more successful with larger holdings that could be utilised despite having similar socioeconomic demographics, but that larger holdings still suffered from extraneous factors such as feed limitations and losses.

3.5.3. Access to veterinary assistance and anthelmintics

Access to health resources such as medicines were associated with owning more adult goats (Pearson's $r = 0.19$, $p = 0.03$), or more livestock overall (Pearson's $r = 0.202$, $p = 0.02$) (S1 File). Such resources may have aided goat survival to market, with more goats sold by those with access to medicine (Pearson's $r = 0.207$, $p = 0.018$) or access to veterinary care (Pearson's $r = 0.24$, $p = 0.006$).

Help was similar at the village level for both access to veterinary assistants (59.1 % total, $\chi^2 = 3.15$, df = 5, $p = 0.68$) and access to medicines for goats (64.4 % total, $\chi^2 = 4.92$, df = 5, $p = 0.43$) (Table S15 and S2 File). However, when assessing groups, TST-study participants were significantly more likely to have access to veterinary assistants compared to Controls ($\chi^2 = 6.45$, df = 1, p-value = 0.011) as well as access to medicine for their goats ($\chi^2 = 6.00$, df = 1, $p = 0.014$).

Medicines were predominantly sourced from veterinary assistants (67.8 % of total), followed by drug boxes (33.3 % of those within the study area), and finally shops (Table S16). Within the study area, both TST-study and non-study control groups utilised veterinary assistants for medicines (52.8 % TST-study vs 57.1 % Controls), but drug boxes were not utilised as heavily by non-study controls (42 % TST-study vs 19 % Controls).

Sustaining access to veterinary assistants or drug boxes might rely on selling a certain amount of anthelmintic, and therefore Plant-TST farmers' use of botanical interventions may break this supply chain. To investigate, TST-study area participants were compared across and within villages (Table 4). Study participants did not differ significantly between groups. However, Plant-TST farmers were more likely to access a veterinary assistant, while TST farmers were more likely to access veterinary medicines compared to their respective controls. While access to veterinary medicine appears uniform, TST group farmers, who were not trained to incorporate botanical interventions, were more likely to seek out medicines while Plant-TST farmers were more likely to seek advice.

Table 4
Odds ratios for access to veterinary help between in-village comparisons*.

Test**	*Access to veterinary assistants*	*Access to veterinary medicines*
Plant-TST vs TST	1.9 (0.48)	1.12 (1)
Plant-TST vs Control	**5.18 (0.027)**	2.06 (0.49)
TST vs Control	4.16 (0.056)	**7.0 (0.01)**
Control-PlantTST vs Control-TST	1.53 (0.543)	3.84 (0.062)

* See Table S15 for count data.
** Two-sided Fisher's Exact Test performed in 2 × 2 contingencies for each occurrence. Shows odds ratios with p values in parentheses. Significant results in **bold**.

4. Discussion

4.1. FPC-TST uptake shows receptiveness and value of integrative veterinary programs

Programs introducing change to farming practices must strive to empower farmers while also being mindful of the context in which farmers operate. Participation in public programs such as farmer field schools can have positive impacts on farmer productivity in East Africa (Davis et al., 2012). In rural Malawi, goat smallholdings are dependent on botanical natural resources for both feed and medicine (Airs et al., 2023a), but goats suffer from high burdens of disease from GINs and malnutrition (Airs et al., 2023b; Chikagwa-Malunga and Banda, 2006; Sargison et al., 2021). Integrative veterinary medicine can bridge this gap by combining local practices (which are driven by local resource availability) with veterinary medicine.

Four years after the end of the study, a large majority of participating farmers still practise the FPC and appear to have adopted at least part of the FPC into their management practices. The FPC steps that farmers still perform include: FAMACHA (69 %), Bottle jaw (85.7 %), Nasal discharge (73.8 %), Body condition scores (85.7 %), and dag/scour (92.9 %) (See Table 1). By comparison, a previous FPC-TST field trial on goat smallholdings in Botswana resulted in only 26 % of study farmers continuing to apply TST unassisted after being provided training (Walker et al., 2015). In the present study, it appears that uptake of the FPC was associated with farmers witnessing improved goat health and productivity while improving farmer confidence: outcomes, that in turn, are associated with a subset of livelihood indicators (see Table 2 and Table S7). In addition to the FPC, Plant-TST farmers continued to target the use of locally available beneficial species, which helped to reduce resource needs overall (see Section 3.4). Additional knowledge of these species and seasonal variation in their nutritional and antiparasitic properties could further enhance their targeted application in TST programs (Cooke et al., 2024).

Beyond the TST-study, farmers in the area were highly receptive to new ideas, with 100 % of TST-study and non-study farmers surveyed in favour of using the FPC if provided with means to do so (see Table 1A). We also found that the majority of non-study controls think the FPC would be useful, despite not having had formal training (see Fig. 2). This may be indicative of the animal health-related difficulties farmers face, but could also speak to the program itself as many TST-study farmers stated they shared information with other farmers (see Section 3.3). It could also be that the increase in knowledge sharing among TST-study farmers is reflective of the increased confidence or expertise in keeping goats resulting from practicing TST. Overall, the survey found the FPC-TST program to be self-sustainable and a success, since farmers were both able and happy to continue to use this approach years later without any outside incentives.

4.2. TST-study participation impacted education and smallholding stability

There were a number of strong and significant correlations between TST-study participation, awareness of parasitic diseases, awareness of goats being sick (due to the FPC), access to veterinary assistance, and access to anthelmintics (S1 File). TST-study participants were better educated about parasites and are willing to share knowledge (see Section 3.3). Together these interactions build a picture of an improved capacity for goat health management resulting from the study. This was in part due to the resources provided during the study so it could be that the sustainability of this approach is limited to the initial investment made. However, while the TST-study did leave participants in a better condition, resources provided were minimal, and some resources like anthelmintics were finite and would have required multiple rounds of replacement. Therefore, it appears that initial training at least has facilitated sustained use of the FPC due to awareness of disease and has helped to reduce the impacts of disease for study farmers.

The evidence base for long-term impacts of livestock programs is minimal, owing to limited funding for retrospective analyses (Wiltsey Stirman et al., 2012). In Botswana, introducing a FPC based TST program resulted in farmers seeing similar benefits to goat herd health and reduced need for anthelmintic interventions relative to interval de-worming of goats at herd level (Walker et al., 2015). In that study a follow-up survey was conducted 12 months after withdrawal of support, finding only 8/35 farmers interviewed to continue to perform TST. Looking more broadly across the literature, farmer field schools, which provide similar training and education without providing extensive resources are often seen as a net benefit to farmers and can increase profits or productivity (Davis et al., 2012; Waddington and Snilstveit, 2014). Goat smallholders may benefit from education and skills alone as these are main drivers motivating goat smallholders to attend farmer field schools (Alcedo et al., 2013), however there is relatively little expertise facilitating farmer field schools on livestock health in comparison to crop agriculture (Braun et al., 2006). When looking at specific examples of strategies to provide interventions and improve smallholder productivity, similar public programs have suffered from limited expertise and assistance following program ends. For instance, an NGO sponsored agriculture project in Côte d'Ivoire was highly successful during sponsorship, but suffered from decreased scale, productivity, livestock mortality (poultry), and limited expertise just 18 months after the project ended (Nordhagen and Traoré, 2022).

Beyond education, there were a number of noticeable differences between TST-study farmers and control farmers. In the original study we were careful to select participants representative of the full spectrum of the community and hence did not select participants from a specific socioeconomic status or demographic. The diversity of respondents remains reflective of the community with no differences in demographic or socioeconomic status found between TST-study and control respondents (see Section 3.1). While no significant socioeconomic differences were found, TST-study participants had larger smallholdings on average (see Table S12). This was true despite the largest smallholdings belonging to some control farmers. This increase in the number of goats was reflected in the increased ability to see benefits of keeping goats, with significantly more farmers selling or using goats compared to non-study controls (Table S12, $\chi^2 = 4.24$, df = 1, p = 0.04). Maintaining more goats comes with more input needs and risks but opens doors for smallholders to gain access to improved trade of their goats. Once study in Zambia found farmers with more goats were significantly more likely to sell goats to traders and potentially generate more profit (Namonje-Kapembwa et al., 2022). Since TST-study participants (particularly Plant-TST participants) said that they use less resources, it may be that the increased smallholding size is more sustainable for those with less resources overall.

4.3. Goat losses and existing barriers to smallholding sustainability

In Malawi, goats managed in agrarian areas can suffer high rates of mortality (Chikagwa-Malunga and Banda, 2006), and the loss of even a single goat from a smallholding can have significant impacts on household security, especially in the places where the average smallholding has only ~3–6 goats (Airs et al., 2023a; Kaumbata et al., 2020).

A primary issue facing goat production is GINs and other parasites, which have major impacts on sustainable livestock production since they increase the nutritional requirements for productivity and can cause high levels of morbidity and death if left uncontrolled (Charlier et al., 2014; Hoste et al., 2005; Rumosa Gwaze et al., 2009). In South Africa a study identified GINs to be more problematic for poorer farmers, farmers who practise tethering, and farmers in grassland areas vs forested areas (Qokweni et al., 2020). Throughout the 2020–2021 study we found that TST improved goat health, controlled GIN infections, reduced resource requirements, and minimised goat deaths (Ventura-Cordero et al., 2025). In the 2025 survey we found that TST-study goat smallholdings were larger and farmers were happy with the health benefits provided by the FPC (see Sections 4.1, 4.2). These findings echo a similar study in Botswana where goat smallholders saw the health benefits of using the FPC following its introduction (Walker et al., 2015). While the TST-study appears to be a self-sustaining means of controlling GINs, many TST-study farmers said that availability of feed was a limitation, so goats may still be suffering from poor nutrition. Nutrition is key since anthelmintics are less effective in malnourished individuals, so may not rescue goats with a high burden of GIN parasites (Morgan et al., 2022). When used effectively, the FPC along with guidance from veterinary assistants or other livestock professionals can help to focus resources to improve overall goat health, rather than relying on anthelmintics as a singular solution. Farmers in the Plant-TST group are an example of this, and were less likely to be limited by health or disease, and claimed to use less resources.

Access to veterinary care continues to constitute a barrier to effective goat health management among Malawi smallholdings. TST-study participants were better connected to health solutions, with higher likelihoods of accessing veterinary care and anthelmintics (see Section 3.5.3), so the study did improve the socioeconomic situation for those involved. However, about half of all surveyed farmers claimed to not see a veterinary professional. Nevertheless, the situation appears to have become drastically more common over recent years, compared to 2000 where only 11 % of farmers said they had ever been visited by a veterinary profession (Mwanza and Mapemba, 2000). This is crucial since medicines among survey respondents were predominantly sourced from veterinary assistants (67.8 % of total), followed by drug boxes (33.3 % of those within the study area), and finally shops (Table S16). Improving access to veterinary assistants may therefore also improve access to medicine when needed. Another benefit of sourcing anthelmintics through veterinary professionals is ensuring the quality of medicine received since poor quality or out of date drugs can pose a threat to effective parasite control (Asrade Mekonnen et al., 2024; Monteiro et al., 1998; Newton et al., 2014; Suleman et al., 2014).

Despite the efforts of smallholders to control GINs and improve goat health, death from unknown causes or losses of goats due to extraneous factors (e.g., dog bites, theft) continue to diminish the benefits of goat smallholdings. Causes of death are various and can go undocumented. For instance, the study area has high levels of plastic pollution that accumulate in the majority of goats and likely lead to haemorrhaging and death (Airs et al., 2024). Of known causes, predation, particularly by dogs, continues to be a considerable issue reported by many individuals here and previously in the study area (S1 File)(Airs et al., 2023a; Chikagwa-Malunga and Banda, 2006). Predation ranked as the second most frequent limitation faced by survey respondents, and is a major issue to small ruminant production in Africa that ranks below disease but still causes significant losses of livestock (Airs et al., 2023a; Chikagwa-Malunga and Banda, 2006; Freeman, 2008; Qokweni et al., 2020; Walker et al., 2015). One study in South Africa estimated predation by medium sized predators to cause a 13 % decrease in small ruminant production (Van Niekerk, 2010). Livestock theft is another major problem reported by smallholders (~55 %), which has been a known issue especially for those who informally allow goats to browse during the dry season (Qokweni et al., 2020; Sidebottom, 2013). In some areas, use of livestock ownership certificates have helped to reduce theft of livestock, but these programs have not been widely introduced and may struggle in areas where informal butchers operate or markets are unregulated (Freeman, 2008; Kaumbata et al., 2020; Rumosa Gwaze et al., 2009). Collectively, goat losses undeniably reduce the impacts of TST and may also disincentivise good farming practice since effort is required to provide proper care to goats.

Because there are so many variables impacting sustainable livestock parasite control, there have been numerous calls to adopt a 'basket of options' approach to encourage uptake of sustainable practices in ways that can empower farmers without significant risk of failure (Krecek and Waller, 2006). In the context of Malawi smallholders, there is a need to further integrate programs that look beyond single issues, since a number of problems are faced by farmers (Rumosa Gwaze et al., 2009). For the TST-study, improved goat health alone could not prevent goat losses. It may be that funding and investment are needed to improve goat housing or identification to minimise theft, while veterinary or animal control infrastructure is needed to reduce the risk of bites from feral and potentially rabid dogs.

4.4. Study limitations and future directions

The study had several limitations, mainly based in the questionnaire nature of the study and the scale and depth of responses garnered. Surveying the opinions of farmers may have introduced bias, which could be reduced though more structured interview techniques. For instance, we were unable to ascertain why some individuals no longer owned or used their FAMACHA cards. Deeper questioning into the contexts of individuals were not explored primarily because time and funding were limiting factors in collecting responses and respondents' time was also deemed valuable. Greater survey depth, or use of interviews would allow for a better individual understanding of circumstances. However, the goal of this study was to determine the general benefit and uptake of FPC to perform TST and assumed that the variety of potential influences occurred more or less homogeneously across the survey area (e.g. impacts of COVID-19).

The other major limitation was the number of participants surveyed. Since the original study required visits to farmers in four different villages every 14 days for 15 months, the study cohort size was limited to those the research team were capable of visiting while also obeying safety precautions and protocols relating to COVID-19. The small sample size was a limitation, impacting statistical power. A loss of some significant differences between groups was identified in mixed-effects models to account for individual villages as a potential confounding factor (S2 File). However, the study design allowed for higher coverage of the farmers included in the original TST trials, as well as controls from closely neighbouring villages. As a result, we were able to more effectively determine if knowledge and practices were disseminated within and between villages. Insights are nevertheless limited to a small geographical area, albeit typifying goat smallholdings in the region, and future studies should consider how widely these apply. In addition to the sample size limitations, smallholders in Malawi keep very few goats overall and use them frequently as tradable assets, so delineating the impact TST and the FPC have on individual goat health is hard to track, especially for rural low-resource smallholders. The study therefore focused on impacts of TST from farmers management practices and opinions, rather than monitoring of goat health directly (which was performed during the initial TST-study).

Ideally, future implementations can grow into larger and more sustained efforts, such as 'training of trainers' networks or field schools where training and materials are provided to perform TST using the FPC at scale (Waddington and Snilstveit, 2014). There is also potential in centralised digitised data collection in order to reach a broader audience and impact a greater number of farmers. For now, this is still not possible for those in rural areas who lack electricity and access to mobile phones. In the study area 39 % of survey respondents lacked access to a mobile phone, so selecting individuals based on their access to resources would inevitably widen socioeconomic inequality by introducing extraneous socioeconomic factors. Alternatively, NGOs and governments can focus resources towards veterinary professionals who in turn can provide farmers both with anthelmintic as well as FPC training and FAMACHA cards in order to better tell when anthelmintics or nutritional interventions are necessary.

5. Conclusions

This study found the vast majority of farmers maintained their use and knowledge of the FPC to perform TST 5 years after being taught, without additional promoting or external resources. Those who use the FPC were less likely to be impacted by disease and poor goat health and proportionally used more goats at market or for consumption. TST farmers also stated that they use less resources while being more confident keeping goats. Farmers taught about targeted feed supplementation of sick goats using bioactive 'nutraceutical' plants continued to apply that knowledge. While most farmers in the original study shared knowledge with other farmers, a lack of professional training and supplies (such as FAMACHA cards) prevented dissemination of the FPC to new farmers. Overall, introducing TST via the FPC has a positive and lasting impact on rural smallholdings, but requires initial investment from larger organisations in order to aid smallholdings at scale.

CRediT authorship contribution statement

Morgan Eric Rene: Writing – review & editing, Funding acquisition. **Andrews Safalaoh:** Writing – review & editing, Supervision, Resources, Project administration, Investigation, Funding acquisition, Conceptualization. **Airs Paul Morgan:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Taro Takahashi:** Writing – review & editing, Writing – original draft, Funding acquisition. **Jan A. van Wyk:** Writing – review & editing, Funding acquisition, Conceptualization. **Jon Tinsley:** Writing – review & editing, Conceptualization. **Winchester Mvula:** Supervision, Investigation.

Ethics and consent to participate and publish

The study was performed in accordance with the LUANAR ethical review no. NS/2018/5 as an extension of a prior BBSRC project (BB/S014748/1). All participants provided informed consent for participation and publication (of anonymous data, images, and GPS location). Details and additional information relating to consent and data collection can be seen in the blank copy of the consent form and survey document.

Statement of animal rights

No animals were used in this study.

Funding

Support for collection of surveys (remuneration of materials and time of survey collectors) was provided via Dr. Paul M Airs from the travel and research grant for fellows at Murray Edwards College at the

University of Cambridge. The underpinning study assessed in this paper was supported by United Kingdom Research and Innovation (UKRI) through the Global Challenges Research Fund, grant numbers BB/S014748/1 and EP/T024356/1.

Declaration of Competing Interest

The authors declare no conflict of interest.

Acknowledgements

Authors would like to thank all participants from both the original study and the retrospective analysis for their time and inputs, as well as assistants at the Lilongwe University of Agriculture and Natural Resources (LUANAR). Authors also thank Murray Edwards College, University of Cambridge for facilitating this work through the research grant for fellows.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.smallrumres.2025.107678.

Data availability

All anonymised raw data, scripts, and survey forms are available at https://github.com/PaulAirs/Malawi_Botanical_Natural_Resources_Goat/.

References

Airs, P.M., Tinsley, J.H.I., Mvula, W., Ventura-Cordero, J., Takahashi, T., Nalivata, P., van Wyk, J.A., Morgan, E.R., Safalaoh, A.C.L., 2024. Prevalence of plastic and hardware foreign bodies among goats at Malawi markets. Animals 14, 147.

Airs, P.M., Ventura-Cordero, J., Gwiriri, L.C., Tinsley, J.H.I., Mvula, W., Lee, M.R.F., van Wyk, J.A., Nalivata, P.C., Takahashi, T., Morgan, E.R., Safalaoh, A.C.L., 2023a. Goat health and management for improved smallholders' livelihoods in central Malawi – A socioeconomic analysis of rural households. Small Rumin. Res. 229, 107114.

Airs, P.M., Ventura-Cordero, J., Mvula, W., Takahashi, T., Van Wyk, J., Nalivata, P., Safalaoh, A., Morgan, E.R., 2023b. Low-cost molecular methods to characterise gastrointestinal nematode co-infections of goats in Africa. Parasit. Vectors 16, 216.

Alcedo, M.J.B., Nishikawa, Y., Maeda, K.-I., Ito, K., 2013. Implication of farmers' motivation in attending farmer livestock school in their behavioural change in goat production and management practices. Trop. Agric. Dev. 57, 94–100.

Asrade Mekonnen, B., Getie Yizengaw, M., Chanie Worku, M., 2024. Prevalence of substandard, falsified, unlicensed and unregistered medicine and its associated factors in Africa: a systematic review. J. Pharm. Policy Pr. 17, 2375267.

[6.8] Banda, J.W., Ayoade, J.A., Karua, S.K., Kamwanja, L.A., 1993. The local Malawi goat. World Anim. Rev. (Engl. Ed.) 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.

Besier, R.B., 2012. Refugia-based strategies for sustainable worm control: factors affecting the acceptability to sheep and goat owners. Vet. Parasitol. 186, 2–9.

Besier, R.B., Kahn, L.P., Sargison, N.D., Van Wyk, J.A., 2016. The pathophysiology, ecology and epidemiology of Haemonchus contortus infection in small ruminants. Adv. Parasitol. 93, 95–143.

Braun, A., Jiggins, J., Röling, N., Van Den Berg, H., Snijders, P., 2006. A global survey and review of farmer field school experiences. Int. Livest. Res. Inst. (ILRI).

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., Morgan, E.R., Rinaldi, L., van Dijk, J., Demeler, J., Höglund, J., Hertzberg, H., Van Ranst, B., Hendrickx, G., Vercruysse, J., Kenyon, F., 2014. Practices to optimise gastrointestinal nematode control on sheep, goat and cattle farms in Europe using targeted (selective) treatments. Vet. Rec. 175, 250–255.

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.

Cooke, A.S., Mvula, W., Nalivata, P., Ventura-Cordero, J., Gwiriri, L.C., Takahashi, T., Morgan, E.R., Lee, M.R.F., Safalaoh, A., 2024. Seasonal dynamics of forage nutrition in smallholder goat production systems in Malawi. Afr. J. Range Forage Sci. 41, 260–269.

Core Team, R.R., 2020. R: A language and environment for statistical computing.

Davis, K., Nkonya, E., Kato, E., Mekonnen, D.A., Odendo, M., Miiro, R., Nkuba, J., 2012. Impact of farmer field schools on agricultural productivity and poverty in east Africa. World Dev. 40, 402–413.

Food and Agriculture Organisation (FAO), 2022. Livestock sector report. https://doi.org/10.4060/cc1073en.

Food and Agriculture Organization (FAO), 2025. The state of food security and nutrition in the World 2022: repurposing food and agricultural policies to make healthy diets more affordable, The State of Food Security and Nutrition in the World. Food & Agriculture Organization of the United Nations (FAO), Rome, Italy. https://doi.org/10.4060/cc0639en.

Freeman, H.A., 2008. Livestock, livelihoods, and vulnerability in Lesotho, Malawi, and Zambia: Designing livestock interventions for emergency situations. ILRI (aka ILCA and ILRAD).

Githigia, S.M., Thamsborg, S.M., Munyua, W.K., Maingi, N., 2001. Impact of gastrointestinal helminths on production in goats in Kenya. Small Rumin. Res. 42, 21–29.

Guinda, E.F.X., Afonso, S.M.S., Fiedler, S., Morgan, E.R., Ramünke, S., Borchert, M., Atanásio, A., Capece, B.P.S., Krücken, J., von Samson-Himmelstjerna, G., 2025. Efficacy of fenbendazole against gastrointestinal nematodes in naturally infected goats in Maputo Province, Mozambique using in vivo, in vitro and molecular assessment. Int. J. Parasitol. Drugs Drug Resist. 27, 100572.

Honhold, N., Petit, H., Halliwell, R.W., 1989. Condition scoring scheme for small east African goats in Zimbabwe. Trop. Anim. Health Prod. 21, 121–127.

Hoste, H., Torres-Acosta, J.F., Paolini, V., Aguilar-Caballero, A., Etter, E., Lefrileux, Y., Chartier, C., Broqua, C., 2005. Interactions between nutrition and gastrointestinal infections with parasitic nematodes in goats. Small Rumin. Res. 60, 141–151.

Kaplan, R.M., Denwood, M.J., Nielsen, M.K., Thamsborg, S.M., Torgerson, P.R., Gilleard, J.S., Dobson, R.J., Vercruysse, J., Levecke, B., 2023. World Association for the Advancement of Veterinary Parasitology (W.A.A.V.P.) guideline for diagnosing anthelmintic resistance using the faecal egg count reduction test in ruminants, horses and swine. Vet. Parasitol. 318, 109936.

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.

Kenyon, F., Greer, A.W., Coles, G.C., Cringoli, G., Papadopoulos, E., Cabaret, J., Berrag, B., Varady, M., Van Wyk, J.A., Thomas, E., Vercruysse, J., Jackson, F., 2009. The role of targeted selective treatments in the development of refugia-based approaches to the control of gastrointestinal nematodes of small ruminants. Vet. Parasitol. 164, 3–11.

Kenyon, P.R., Maloney, S.K., Blache, D., 2014. Review of sheep body condition score in relation to production characteristics. N. Z. J. Agric. Res. 57, 38–64.

Krecek, R.C., Waller, P.J., 2006. Towards the implementation of the "basket of options" approach to helminth parasite control of livestock: emphasis on the tropics/subtropics. Vet. Parasitol. 139, 270–282.

Learmount, J., Stephens, N., Boughtflower, V., Barrecheguren, A., Rickell, K., Massei, G., Taylor, M., 2016. Three-year evaluation of best practice guidelines for nematode control on commercial sheep farms in the UK. Vet. Parasitol. 226, 116–123.

Maganga, A., Chigwa, F., Mapemba, L., 2015. Goat and goat meat markets in selected districts of Malawi: Value chain, structure and efficiency. Livest. Res. Rural Dev. 27, 28560.

Mahieu, M., Arquet, R., Kandassamy, T., Mandonnet, N., Hoste, H., 2007. Evaluation of targeted drenching using Famacha method in Creole goat: reduction of anthelmintic use, and effects on kid production and pasture contamination. Vet. Parasitol. 146, 135–147.

Mavundela, S., Dzemo, W.D., Thekisoe, O., 2025. Anthelmintic resistance in gastrointestinal nematodes on communally reared sheep farms of the King Sabata Dalindyebo Municipality, South Africa. Parasitol. Res. 124, 86.

Monteiro, A.M., Wanyangu, S.W., Kariuki, D.P., Bain, R., Jackson, F., McKellar, Q.A., 1998. Pharmaceutical quality of anthelmintics sold in Kenya. Vet. Rec. 142, 396–398.

Morgan, E.R., Lanusse, C., Rinaldi, L., Charlier, J., Vercruysse, J., 2022. Confounding factors affecting faecal egg count reduction as a measure of anthelmintic efficacy. Parasite 29, 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.

Mwanza, R., Mapemba, J., 2000. Crisis mitigation in livestock dependent systems: concern, universal experiences and challenges in promotion of livestock production in Dedza District. Dedza, Malawi. In: Banda, J., Chagunda, M. (Eds.), in: Proceedings of the Regional Conference Held at. Malawi Institute of Management, Lilongwe, Malawi.

Namonje-Kapembwa, T., Chiwawa, H., Sitko, N., 2022. Analysis of goat production and marketing among smallholder farmers Zambia. Small Rumin. Res. 208, 106620.

Newton, P.N., Tabernero, P., Dwivedi, P., Culzoni, M.J., Monge, M.E., Swamidoss, I., Mildenhall, D., Green, M.D., Jähnke, R., de Oliveira, M.D.S., Simao, J., White, N.J., Fernández, F.M., 2014. Falsified medicines in Africa: all talk, no action. Lancet Glob. Health 2, e509–e510.

Nordhagen, S., Traoré, A., 2022. Group-based approaches to nutrition-sensitive agriculture: insights from a post-project sustainability study in Côte d'Ivoire. Food Secur 14, 337–353.

Olah, S., van Wyk, J.A., Wall, R., Morgan, E.R., 2015. FAMACHA©: a potential tool for targeted selective treatment of chronic fasciolosis in sheep. Vet. Parasitol. 212, 188–192.

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.
Romney, D.L., Sendalo, D.S.C., Owen, E., Mtenga, L.A., Penning, P.D., Mayes, R.W., Hendy, C.R.C., 1996. Effects of tethering management on feed intake and behaviour of Tanzanian goats. Small Rumin. Res. 19, 113–120.
Rumosa Gwaze, F., Chimonyo, M., Dzama, K., 2009. Communal goat production in Southern Africa: a review. Trop. Anim. Health Prod. 41, 1157–1168.
Sabatini, G.A., de Almeida Borges, F., Claerebout, E., Gianechini, L.S., Höglund, J., Kaplan, R.M., Lopes, W.D.Z., Mitchell, S., Rinaldi, L., von Samson-Himmelstjerna, G., Steffan, P., Woodgate, R., 2023. Practical guide to the diagnostics of ruminant gastrointestinal nematodes, liver fluke and lungworm infection: interpretation and usability of results. Parasit. Vectors 16, 58.
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.
Suleman, S., Zeleke, G., Deti, H., Mekonnen, Z., Duchateau, L., Levecke, B., Vercruysse, J., D'Hondt, M., Wynendaele, E., De Spiegeleer, B., 2014. Quality of medicines commonly used in the treatment of soil transmitted helminths and giardia in ethiopia: a nationwide survey. PLoS Negl. Trop. Dis. 8, e3345.
[6.51] Van Niekerk, H.N., 2010. The cost of predation on small livestock in South Africa by medium-sized predators [Masters dissertation]. University of the Free State Bloemfontein, South Africa.
van Wyk, J.A., 2001. Refugia–overlooked as perhaps the most potent factor concerning the development of anthelmintic resistance. Onderstepoort J. Vet. Res. 68, 55–67.
van Wyk, J.A., Bath, G.F., 2002. The FAMACHA system for managing haemonchosis in sheep and goats by clinically identifying individual animals for treatment. Vet. Res. 33, 509–529.
van Wyk, J.A., Hoste, H., Kaplan, R.M., Besier, R.B., 2006. Targeted selective treatment for worm management–how do we sell rational programs to farmers? Vet. Parasitol. 139, 336–346.
Ventura-Cordero, J., Airs, P.M., Safalaoh, A.C.L., Mvula, W., Cooke, A.S., Gwiriri, L.C., Machekano, H., Wagstaff, P., Nyamukondiwa, C., Lee, M.R.F., Takahashi, T., van Wyk, J., Nalivata, P.C., Morgan, E.R., 2025. Targeted selective supplementation with local plants sustainably improves goat health and decreases anthelmintic drug need on Malawi smallholdings. 06 May 2025, PREPRINT (Version 1) available at Research Square [https://doi.org/10.21203/rs.3.rs-6235021/v1].
Villaquiran, M., Gipson, T.A., Merkel, R.C., 2004. Body condition scores in goats. Institute for Goat.
Waddington, H., Snilstveit, B., 2014. Farmer field schools for improving farming practices and farmer outcomes. Low. MiddleIncome Ctries. Campbell Collab. https://doi.org/10.4073/csr.2014.6.
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.
Wiltsey Stirman, S., Kimberly, J., Cook, N., Calloway, A., Castro, F., Charns, M., 2012. The sustainability of new programs and innovations: a review of the empirical literature and recommendations for future research. Implement. Sci. 7, 17.
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 22/09/2025].