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Enhancing livestock production and food safety through a one health approach in resource poor settings

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Enhancing livestock production and food safety through a one health approach in resource poor settings

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Editorial: Enhancing livestock production and food safety through a One Health approach in resource poor settings

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KEYWORDS

One Health, animal source food, systems approach, transformational knowledge, added value

Editorial on the Research Topic
Enhancing livestock production and food safety through a One Health approach in resource poor settings

This Research Topic aimed to collate scientific studies that demonstrate the theoretical foundation and operationalization of One Health considering the animal source food systems and livelihoods. We therefore paid attention to select studies that, from the start, applied system thinking and transdisciplinarity approaches, and tried to frame the food system problem at hand as part of a bigger system with discussions that addressed socio-ecological complexities, challenges and solutions based on clear engagement and equity. In the submissions we particularly looked for evidence of the One Health indicators: (i) collaboration, (ii) added value, (iii) system thinking, (iv) transdiciplinarity, (v) participation of stakeholders, (vi) gender and equity, (vii) implementation of action based on findings, (viii) sustainability.

Following a One Health approach requires transdisciplinarity and participation of different stakeholders (1, 2). An important challenge however, is to ensure that everybody understands the same thing. To explore how participants in a study on antimicrobial use and resistance in Uganda and Kenya understand questions in a survey, and to find ways to restructure and clarify the survey, Wenemark et al. present cognitive interviews as a promising method. Their approach helps to validate a questionnaire, and thus improve the quality of a survey. In particular for complex research questions following a One Health approach, this type of survey validation in our view is recommended.

Focusing on stakeholder participation, Ngwili et al. used focus group discussions in Uganda with different stakeholder groups along the pork value chain, combined with

key informant interviews. Their findings demonstrate fragmented knowledge on the zoonotic parasite *T. solium* in different stakeholder groups, which in turns helps to devise content of stakeholder specific intervention programs. Asakura et al.'s work in Tanzania provide another example of how participatory approaches further illuminate complex problems and help to find a way forward. They added insights using participatory rural appraisals to a previous body of knowledge on brucellosis control in Tanzania, which was derived with quantitative tools, and with this expect to design more sustainable and acceptable community-based disease control programs. Similarly, by using stakeholder participation, Kemp et al. provide insight into common practices and awareness of farmers and veterinary professionals of antimicrobial use and antimicrobial resistance in Kenya. The study suggests sustaining several behavioral interventions in tandem with legislative reforms could reduce inappropriate prescription.

The advantages of combining qualitative and quantitative approaches were shown by Adjei et al., when assessing food safety challenges in the beef value chain in Ghana. Not only included the study several pathogens, but their occurrence could be linked to knowledge on food safety among butchers and retailers.

The importance of considering the "added value" is illustrated by Soare et al. Any intervention leads to some change in a system, ideally leading to benefits beyond the initially targeted areas. The authors thus argue, that pre-identifying potential synergies and trade-offs in disease control interventions is important during the design stage.

Lam et al. provide a rare example of how One Health thinking is applied already at the conceptual stage of a project in Vietnam. They integrate One Health in a Theory of Change framework to help characterize the pathways to safer pork in Vietnam.

Knowledge of the extent of a problem is not sufficient to find sustainable solutions; a fact that is presented by Davis et al. Based on findings from focus groups discussions in Tanzania, they report a range of animal health seeking strategies of livestock owners and identified access to resources and trust in health care providers as important factors influencing the ability of livestock farmers to act to improve livestock health.

System thinking by collecting evidence for policy is the approach chosen by Haile et al. The prevalence of *E. coli* in raw beef is determined across Ethiopia's capital and the resistance to antimicrobials is established.

Seko et al.'s interdisciplinary study applies quality theory based on an information economics approach to the user oriented quality perception of braised (dibiterie) meat in Dakar, Senegal. The study finds that consumer decisions if and where to buy braised meat, are based on subjective preferences and are not linked to food safety.

The One Health basic principles found in most studies, were transdisciplinarity and system thinking, followed by implementation of findings and stakeholder participation. Sustainability was found in only one study, while the indicators gender and equity were completely absent. Encouragingly, most studies aim to implement "better action", but are missing examples of studies that show this process. This in turn means a lack of examples that demonstrate the "added value" of using a One Health approach even though its importance is stressed by Soare et al. This collection of papers features good examples of interdisciplinarity, but reaching true transdisciplinarity seems more of a challenge. Most studies focused on participation of different stakeholders, which is a positive development and has led to new insights on how challenges at the animal and human health interface can be addressed, that may indicate a positive trend toward system thinking.

We further observed that authors struggled to tease out the added value of collaborative work resulting from the One Health approach. A likely reason could be, that at the design stage of the studies, classical epidemiological principles are used and the One Health focus is an add-on at a later stage. It should be the other way round. The complexity at hand should be initially looked at from a One Health perspective followed by "zooming in" on a particular research question around collaboration and impact. With such an approach, it is more likely that factors linked to a particular problem are comprehensively considered allowing the discussion of the results within the system and not as stand-alone findings. The ownership of the produced co-designed transformational knowledge should then ideally lead to cost-effective and sustainable interventions in food safety.

Overall, it becomes clear that an adapted and improved Research Topic as follow up to this special edition is justified to provide a platform for One Health research and its implementation, incorporating the One Health principle from the onset. The study design should clearly show the process of identifying the problem and the One Health framework used to shape the research or intervention and the validation of findings involving all actors. While the One Health approach is gaining more traction, researchers in food safety are still finding their feet on how to present such work. Likewise, researchers claiming to use the One Health approach still need to develop their skills further. A future issue should thus center on practical cases and best practice to facilitate learning, while focusing on factors of success and failures in operationalizing One Health in food systems.

Author contributions

BB and KK developed the first draft. BB, BW, HN-V, and KK revised the draft and approved the final version. All authors developed the first structure. All authors contributed to the article and approved the submitted version.

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Conflict of interest

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

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A Cross-Sectional Survey of the Knowledge, Attitudes, and Practices of Antimicrobial Users and Providers in an Area of High-Density Livestock-Human Population in Western Kenya

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Background: Antimicrobial resistance (AMR) is one of the most important global health crises in recent times and is driven primarily by antimicrobial consumption. In East Africa, there is a paucity of data regarding the knowledge, attitudes, and practices (KAP) related to antimicrobial use (AMU). We investigate the ways in which antimicrobial users in the veterinary sector accessed veterinary antimicrobials, and common behaviors of veterinary antimicrobial users and prescribers associated with AMU and AMR.

Methods: In total, 70 farmers, staff at 49 agricultural-veterinary antimicrobial shops (agrovet staff) and 28 veterinary animal healthcare workers or veterinary surgeons (veterinary professionals) were interviewed in Busia county, western Kenya in 2016 using a standard questionnaire as a framework for structured interviews. Data recorded included participant demographics, level of education, access to and sources of veterinary antimicrobials, prescribing patterns, and knowledge of AMR and antimicrobial withdrawal periods.

Results: The majority of antimicrobials were accessed through informal means, purchased from agroveterinary shops; more than half of staff did not hold nationally mandated qualifications to advise on or sell veterinary antimicrobials. Approximately 40% of veterinary antimicrobials were sold without a prescription and it was noted that both price and customer preference were important factors when selling antimicrobials in almost all agrovet shops. Knowledge of the dangers associated with AMR and AMU were mostly superficial. Treatment failure occurred often, and there was a lack of differentiation between AMR and simply treatment failure.

Conclusion: In this study area in East Africa with high-density human and livestock populations, AMU was primarily for maintenance of livestock health. These findings have highlighted several aspects surrounding inappropriate access to antimicrobials, and as such require attention from policy makers concerned with AMR in both livestock and

human medicine sectors. Improving prescribing practices and ensuring a minimum level of general education and awareness of prescribers, as well as expanding the role of agrovet staff in antimicrobial stewardship programmes, may help begin to mitigate the maintenance and transmission of AMR, particularly amongst livestock.

Keywords: AMU, AMR, KAP, antimicrobial stewardship, access to antimicrobials

INTRODUCTION

Antimicrobials are essential for maintaining animal health in livestock production systems, but inappropriate dispensing and dosing, poor quality of drugs, overuse, and self-medication of antimicrobials can select for and exacerbate the emergence, transmission, and persistence of antimicrobial resistance (AMR) (1–3). In East Africa, there is high demand for animal food products to support the rapidly growing population, and this demand is largely fulfilled by the high proportion (83%) of people engaging in crop and livestock farming (4). In some parts of the region, such as in the Lake Victoria crescent ecosystem, increased demand has prompted the shift from small holder farming to greater commercialization and intensification (5), which often necessitates increased antimicrobial use (AMU) for prophylaxis and treatment of animals in order to maintain animal health (6). Livestock may act as reservoir of AMR bacteria, with potential for widespread transmission between humans and animals as a result of close contact between the two, or via the food chain. The former is an issue when there are high densities of both humans and livestock (4), as is the case in both rural and urban Kenya, where this study was conducted (7, 8).

There are significant ramifications of AMR amongst livestock; nine of the 14 classes of antimicrobials considered to be "critically important" for human health are used in both human and livestock health. Three of these (3^{rd}-5^{th} generation cephalosporins, fluoroquinolones, and polymyxins) are considered to be highest-priority critically important antimicrobials (HPCIAs) for human health (9). Antimicrobial use in livestock production is predicted to increase by up to 67% by 2030; as increased AMU may result in significant negative impacts on animal welfare and food security, as well as reducing efficacy of antimicrobials which have crossover for human health (10). However, it is important to note that owing to the complex epidemiology of AMR, the quantifiable contribution that AMU in livestock has on the emergence, transmission, and maintenance of AMR in humans is still debatable. Studies have shown that similar strains of AMR bacteria are found in both food animals and humans (11), as well as plasmid-mediated resistance in *Escherichia coli* to polymyxins (mcr-1), originating from food animals (12). Despite this, other argue that transfer of animal to human resistance genes is negligible and that reduction of AMU in food-producing animals may have a negative effect on food safety and human health (13). Regardless of the debate, such data to is mostly absent in sub-Saharan Africa.

In many sub-Saharan African countries, including Kenya, there is a paucity of data on the prevalence of both AMR and AMU, as the combined realities of underfunded veterinary healthcare systems, limited regulatory capacities and lack of systematic, national, or regional surveillance systems undermine efforts to promote prudent AMU and control AMR (14, 15). Indeed, Kenya is part of a global effort to improve surveillance capacity in line with its National AMR Action Plan.

Many existing studies examining antimicrobial treatment patterns typically rely on self-reported data, showing that antimicrobials are almost always purchased without prescriptions at "agrovets" (shops which stock agricultural and veterinary antimicrobials as well as other agro-veterinary products) (16–19). Agrovets are often staffed with pharmaceutical technicians (20) who have obtained formal training in animal sciences. As such "agrovet staff" may sell antimicrobials, but crucially cannot prescribe them. To comply with local law, agrovet owners may be veterinarians and would thereby be able to legally prescribe antimicrobials. Private veterinary professionals travel to farms at the request of farmers where they provide advice, treat animals, or prescribe veterinary drugs. Veterinary professionals would typically have professional qualifications specifically enabling them to prescribe veterinary antimicrobials and are governed by the Veterinary Surgeons and Veterinary Paraprofessionals Act of the Government of Kenya (21). Together, antimicrobial sellers and prescribers are responsible for, and play a pivotal role in, highlighting issues that surround AMU and AMR, as well as being the front line of antimicrobial stewardship (22). Relatively few studies (23) have examined the knowledge, attitudes, and practices (KAP) of antimicrobial users and prescribers, and such studies are critically required in order to identify risky behaviors and target them for intervention.

In this study, we assessed the way in which antimicrobials were accessed and the general awareness and common behaviors relating to antimicrobial purchase and prescription amongst farmers, agrovet shop staff and veterinary professionals in a small holder livestock production system in western Kenya (24).

METHODS

Study Area and Population

A cross-sectional study investigating how farmers, agrovets, and veterinary paraprofessionals access and prescribe antimicrobials was conducted in Busia county, western Kenya in 2017. The region was selected for study as it supports the highest human and animal population densities in eastern Africa with approximately 893,681 people (25), 83% of which engage in livestock production (4); the region is also broadly representative of other communities spanning the Victoria Lake Basin in Kenya, Uganda, and Tanzania.

Busia county is sub-divided into seven "sub-counties." Within each sub-county, 10 farms were randomly selected for interview as a convenience, but also to capture the spatial distribution and diversity of farming practices across the county. Systematic interviewing of agrovet shops and veterinary professionals (**Figure 1**) was conducted with assistance from the sub-county veterinary officer from each sub-county. Interviews were sought with the most senior member of staff in all locatable agrovet shops in the county, except when shops were closed on more than two occasions during repeat visits. A comprehensive list of all known veterinary professionals was collected from sub-county district officers and veterinary professionals were recruited by phone. Veterinary professionals were who agreed to participate were interviewed separately from agrovet shops, at a convenient location to each participant.

Questionnaire Design and Piloting

All recruited participants were interviewed orally using a questionnaire as a framework. Questionnaires were designed in Adobe® Acrobat® Pro DC (Adobe, San Jose, United States) and coded electronically using AppSheet® (AppSheet c/o Solvebot Inc., Seattle, Washington). Participants were interviewed in English or Kiswahili by bilingual Kenyan research members. Answers were given verbally by the participant and recorded verbatim as transcribed text into the coded questionnaire on a mobile phone or tablet, by the interviewer. Questions were designed to determine the participant's education level, access to veterinary antimicrobials, prescribing patterns of antimicrobials, knowledge of antimicrobials, resistance, and withdrawal periods. Questions specifically asked of farmers focused on access to veterinary antimicrobials, basic information on animals kept (date of acquisition, vaccination status), common diseases, and understanding of AMR and withdrawal periods. Veterinary professional and agrovet staff questionnaires focused primarily on sales/prescription patterns and responsible use of antimicrobials.

Questionnaires were piloted on field team staff. Minor refinements to question wording were made to better reflect local conditions before conducting a further pilot on a sub-county veterinary officer. After these pilot tests, the questionnaire was then used in the field. A summary of all questions is presented in **Supplementary Table 1**.

All questionnaire data can be found at https://github.com/Steven-Kemp/Kenya_KAP.

Data Analysis

Transcribed answers for each question were imported into Microsoft Excel 2016 (Microsoft Corporation, Redmond, USA). Descriptive analysis including frequencies and percentages for categorical variables (gender, age, education level) were calculated using SPSS Statistics v25.0 (IBM SPSS Statistics for Windows Version 25.0, New York: IBM Corp). Open-ended questions were analyzed on a question-per-question basis using a thematic approach (26). Briefly, all responses were imported into excel and read twice for familiarization, data were coded, and then individual themes were generated and checked independently. Finally, themes were reviewed once again, refined, and then presented. Also using SPSS v25.0, the Fisher's exact test was used to compare specific training undertaken by antimicrobial providers relating to antimicrobial prescription.

Maps were constructed using QGis v3.10 (QGIS Development Team, http://qgis.osgeo.org/). Figures were constructed in Prism v9.1.1.

Ethical Approval

Ethical approval was obtained from the Institutional Research Ethics Committee of the International Livestock Research Institute (ILRI-IREC2016-03), and the University of Liverpool Veterinary Science Research Ethics Committee (VREC387). All participants gave informed, written consent before participation in the study.

RESULTS

Participant Demographics and Education

A total of 70 farmers, 49 staff at agrovet shops, 27 AHAs, and 1 veterinary surgeon were recruited (**Table 1**). As recognized professionals, the veterinary surgeon and AHAs were considered together in our analysis and are referred to as "veterinary professionals" throughout. The predominant age bracket for all groups surveyed was 25–44. The majority of agrovet staff were either agrovet assistants (79.6%) or shop owners (18.4%). Only 44.9% of agrovet staff had obtained college or university education, compared to 89.2% of veterinary professionals. For farmers, the majority (47.1%) had completed at least secondary school education. Significantly more veterinary professionals had received specific training in livestock health and disease ($P = 0.01$) than agrovets. Only 42.9% of agrovets and 82.1% of veterinary professionals had received specific training to dispense veterinary antimicrobials. A large proportion of agrovets cited informal training (44.9%) as their primary source of knowledge, compared to 92.9% of veterinary professionals who obtained a professional qualification awarded by a college or university. However, 7.1% ($n = 2$) of veterinary professionals interviewed stated that they did not have university education, therefore could not be called veterinary professionals.

Access to Antimicrobials and Common Sales Patterns

All veterinary antimicrobials were purchased directly from agrovet shops, where both farmers and veterinary professionals can purchase antimicrobials from. Antimicrobials and vaccines were distributed to local agrovets shops by two larger wholesale agrovet shops (one within Busia county, one in neighboring Bungoma county) who obtained antimicrobials directly from manufacturers and through their supply chains.

Farmers reported no restrictions (in amount or class) when purchasing antimicrobials from agrovet shops, even without a valid prescription. More than half (57.1%) of veterinary professionals stated that they provided a prescription for farmers to obtain antimicrobials, with the remainder treating animals with their own stock and billing farmers separately for these. This agreed with responses from agrovet staff who reported that they (60%) often dispensed antimicrobials against a prescription.

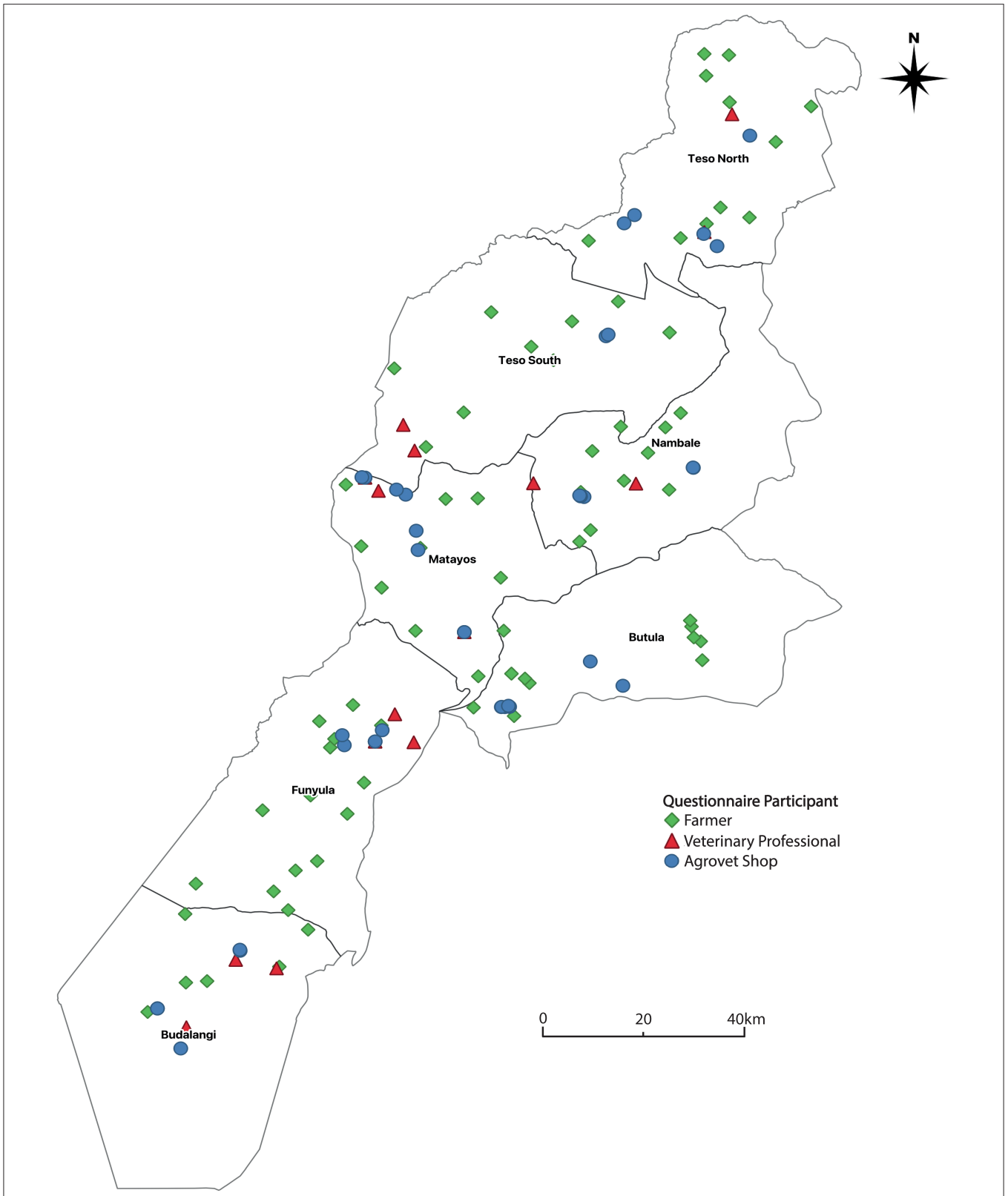

FIGURE 1 | Map of Busia county, western Kenya, indicating the locations of all interviewed farmers, agrovet staff (within their shops) and veterinary professionals.

TABLE 1 | Participant demographics and education.

Characteristics		Agrovet staff ($n = 49$)		Veterinary professionals ($n = 28$)		Farmers ($n = 70$)	
		n	%	*n*	%	*n*	%
Gender	Male	25	51.0	27	96.4	48	68.6
	Female	24	49.0	1	3.6	22	31.4
Age group	18–24	8	16.3	–	–	2	2.9
	25–44	35	71.4	20	71.4	40	57.1
	45–64	5	10.2	6	21.4	17	24.3
	65+	1	2.0	2	7.1	11	15.7
Job position	Animal healthcare worker	1	2.0	14	50.0	–	–
	Artificial insemination technician	–	–	1	3.6	–	–
	Sub-country veterinary officer	–	–	3	10.7	–	–
	Agrovet assistant	39	79.6	1	3.6	–	–
	Laboratory staff/vet technician	1	2.0	3	10.7	–	–
	Livestock Officer	–	–	5	17.6	–	–
	Veterinarian	–	–	1	3.6	–	–
	Manager	1	2.0	–	–	–	–
	Owner	9	18.4	–	–	–	–
Length of time at job	<1 Year	14	28.6	1	3.6	–	–
	1–2 Years	4	8.2	–	–	–	–
	>3 Years	31	63.3	27	96.4	–	–
Highest education level	No formal education	–	–	–	–	4	5.7
	Primary education	–	–	–	–	24	34.3
	Secondary education	27	55.1	3	10.7	33	47.1
	College (certificate/diploma)	20	40.8	23	82.1	7	10
	University	2	4.1	2	7.1	2	2.9
Nature of training	Professional qualification	8	16.3	26	92.9	–	–
	Pharmaceutical company	15	30.6	–	–	–	–
	None/Informal training	22	44.9	2	7.1	–	–
	Cannot remember	3	6.1	–	–	–	–

Direct observations when visiting such premises confirmed that agrovet shops did sell antimicrobials with no prescription, as well as dispensing single syringes of formula antimicrobials or partial-treatments to farmers, even though this is a contravened practice in Kenyan Law (27).

Participants were asked to indicate the most commonly sold or prescribed antimicrobials (agrovet staff and veterinary professionals) or most commonly purchased (farmers), and a total of 26 different antimicrobials were reported by all groups. Oxytetracycline and penicillin-streptomycin were the two most commonly sold or prescribed antimicrobials by agrovet staff and veterinary professionals (**Table 2**), followed by sulfonamides. The majority of farmers opted to purchase oxytetracycline as their primary drug of choice (78.6%) from agrovet shops. There was no reported use or sale/prescription of 3rd+ generation cephalosporins or fluoroquinolones. There was only a single occasion whereby a farmer purchased polymyxins (colistin), but these drugs are available at agrovets when requested.

There were large inconsistencies in the reported use of antimicrobials. Antimicrobials were predominantly reported as being used therapeutically (i.e., not for growth promotion or prophylaxis) by farmers (85.7%) and veterinary professionals (100%) and sold for therapeutic purposes by agrovets (98.0%). However, prophylactic use of antimicrobials was subsequently indicated by 37.1% of farmers and 28.6% of veterinary professionals and sold as such by 38.8% of agrovets in a later question in the questionnaire. Use of antimicrobials as growth promoters was reported by 37.1% farmers, but not sold as such by agrovet shops or prescribed by veterinary professionals.

The most common diseases that antimicrobials were cited as being purchased to treat were East Coast fever (theileriosis), anaplasmosis, trypanosomiasis, diarrhea, and general respiratory diseases.

Advice and Considerations Given at Point of Sale Regarding AMU, AMR, and Withdrawal Periods

Most farmers reported first seeking the advice of a veterinary professional before purchasing antimicrobials (78.6%). More than half of farmers (54.3%) never requested specific antimicrobials without first discussing with either agrovet staff or veterinary professional. A small minority of farmers (12.9%) purchased antimicrobials without obtaining any advice from an agrovet or a prescription from a veterinary professional. Such farmers stated they did so "using [their] own knowledge" or "already had a prescription from a veterinary officer from

TABLE 2 | List of the most commonly used/purchased/prescribed antimicrobials according to farmers, agrovets, and veterinary professionals, to treat livestock.

Antimicrobial	Veterinary professionals (*n* = 28)		Agrovet staff (*n* =49)		Farmers (*n* =70)	
	n	%	*n*	%	*n*	%
Oxytetracycline	26	92.9	46	93.9	55	78.6
Penicillin-streptomycin	27	96.4	39	79.6	33	47.1
Sulfachloropyrazine	9	32.1	27	55.1	–	–
Sulfadimidine	9	32.1	13	26.5	2	2.9
Trimethoprim and Sulfadiazine	9	32.1	8	16.3	4	5.7
Tylosin and Doxycycline	–	–	18	36.7	2	2.9
Sulfamethoxazole	3	10.7	8	16.3	–	–
Gentamicin	6	21.4	–	–	1	1.4
Tylosin	4	14.3	–	–	–	–
Tetracycline	1	3.6	3	6.1	–	–
Fosfomycin and Tylosin	–	–	4	8.2	–	–
Sulfamethoxazole and Trimethoprim	–	–	4	8.2	–	–
Erythromycin	2	7.1	–	–	1	1.4
Gentamicin and Doxycycline	–	–	3	6.1	–	–
Neomycin	–	–	3	6.1	–	–
Cefalexin	1	3.6	–	–	1	1.4
Metronidazole	1	3.6	–	–	1	1.4
Ampicillin	1	3.6	–	–	–	–
Streptomycin	1	3.6	–	–	–	–
Amoxicillin	–	–	1	2.0	–	–
Dexamethasone**	–	–	1	2.0	–	–
Erythromycin and Oxytetracycline	–	–	1	2.0	–	–
Colistin*	–	–	–	–	1	1.4

Up to five "most common" antimicrobials were volunteered; therefore, each antimicrobial was counted once each time it featured in the respondents' answer.
**Highest priority critically important antimicrobials.*
***Not an antimicrobial but described by the respondent as one.*

a previous consultation". A small proportion of farmers also reported using antimicrobials previously prescribed or purchased, "[having antimicrobials leftover] from previous use."

In agrovet shops the primary consideration when selling antimicrobials was customer preference (65.3%). Veterinary professionals' primary consideration was antimicrobial effectiveness (57.9%) and then cost (39.3%). Farmers were primarily concerned with antimicrobial cost (44.3%), followed by effectiveness (40.0%). As cost was a common consideration, the sale price of various antimicrobials was collected (**Figure 2**). The average price of oxytetracyclines were cheaper than penicillin/streptomycin; this is consistent with the finding that oxytetracyclines were the most commonly sold antimicrobial in agrovets shops. A small minority of farmers also considered antimicrobial availability and the distance they needed to travel to purchase specific types of antimicrobials as their primary point of consideration (5.7%). Specific agrovet shops were chosen by farmers for several reasons including the "close distance to [their] farms," ability to "get drugs on credit" and for "wide selection" and "good stock availability."

The most commonly offered information regarding antimicrobials at point of sale or prescription differed significantly between antimicrobial sellers and antimicrobial providers; 61.2% of agrovet staff gave directions for use of antimicrobials, compared to only 25.0% of veterinary professionals, where they were provided to the farmer to use themselves. Similarly, significantly more veterinary professionals chose to give no information at all (50.0%) compared to 18.4% of agrovets (**Figure 3**). The other two most common cited pieces of information provided to farmers were withdrawal periods and dosage instructions, though in all cases, these were reported to be read from the packaging.

Understanding of AMR

Participants rarely recognized the terms "antimicrobial resistance" or "antibiotic resistance." Once given a definition, many suggested that they had heard of it, but did not recognize the specific terminology. A large proportion of agrovets (69.4%), veterinary professionals (39.3%), and farmers (47.0%) did not know the causes of AMR. Of those who had some knowledge of causes, the most common response was underdosing (significantly more veterinary professionals than agrovets) and prolonged use (**Figure 4**). Some farmers additionally reported "bacteria mutation" (2.9%), "misdiagnosis by an agrovet/veterinary professional" (15.9%), and using "counterfeit antimicrobials" (1.4%) as causes of AMR. Participants who were unsure about the cause of AMR instead guessed: "when you treat an animal and it doesn't respond," "when the animal is tired, the antibiotic will not work," and "cheap drugs no longer work, but the more expensive ones do." Of those respondents who were familiar with AMR, they suggest that there may be resistance to oxytetracyclines, penicillin-streptomycin, and sulfonamides though no formal resistance testing was routinely undertaken.

Knowledge of withdrawal periods was mostly superficial amongst farmers. Contrary to EU regulations, withdrawal periods are usually specific to the route of administration e.g., antimicrobials administered to cattle may have a nil milk withdrawal due to penetration into the udder but would have a meat withdrawal period—this is not often defined on antimicrobial packaging (**Supplementary Figures 1A–D**). However, with respect to withdrawal periods or definitions, 12.9% had "no understanding" (never heard of withdrawal period before), 34.3% had "minor understanding" (had heard of it but quoted incorrect withdrawal periods for animal food products), and 27.1% had "good understanding" (good knowledge and accurate recall of withdrawal periods of each antimicrobial they regularly treated animals with). The remainder (18.6%) stated they sometimes referred to antimicrobial packaging for withdrawal period times. The majority of farmers stated that they did not sell or consume animals or animal products during withdrawal periods (75.7%), though some reported that they purposefully chose to ignore withdrawal period recommendations (17.1%). Commonly farmers fed antimicrobial residue-containing milk to their dogs (14.3%) or allowed calves to suckle during treatment (44.3%). One farmer stated that

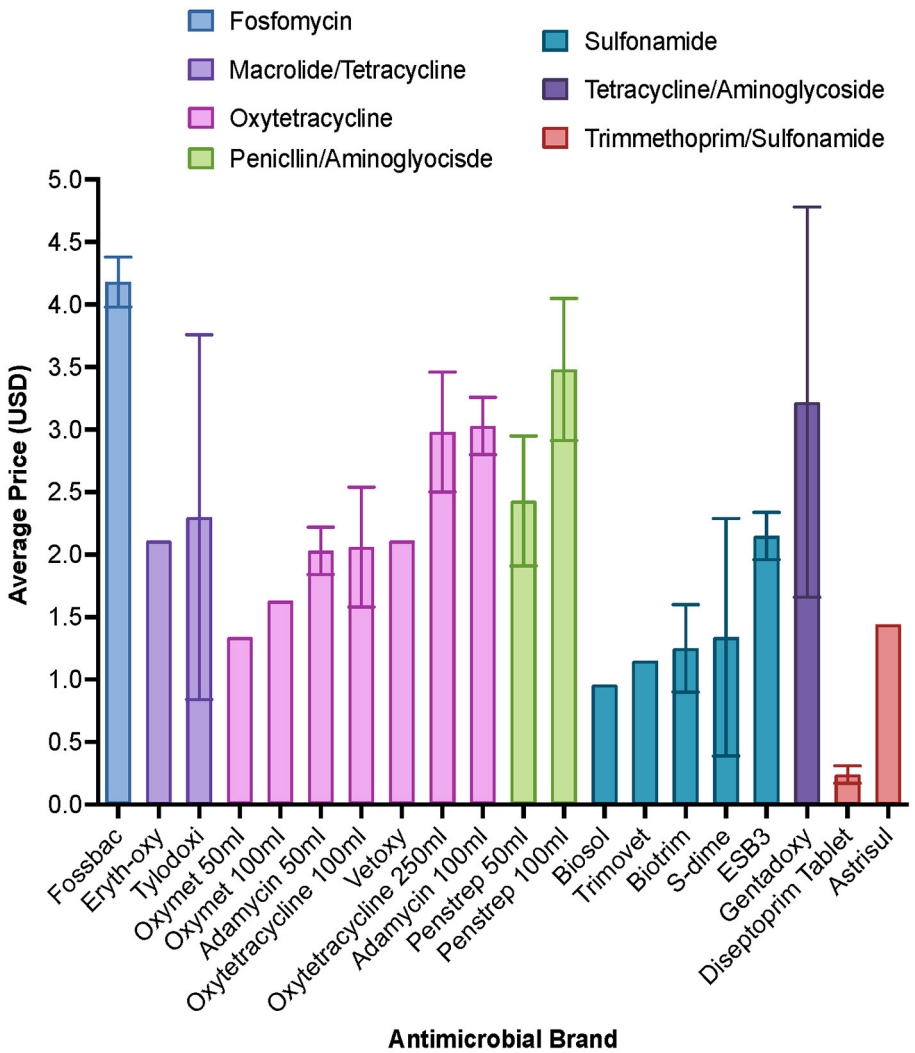

FIGURE 2 | Average sale cost of antimicrobials from 49 agrovet shops across Busia county. Error bars represent standard deviation where more than one agrovet shop reported pricing data.

they regularly gave contaminated milk to their animals, despite understanding the danger of consuming residues: "[I] give to the calves and the dog. [I] understand that resistance may develop in these animals, but [I] choose to ignore it to avoid waste."

Management of Drug Failure

Only one instance of a highest-priority critically important antibiotics (HPCIA) was reportedly sold or purchased during the study—colistin. No agrovet staff and only a veterinary professional (3.6%) had heard the term "HPCIA" before. The majority of veterinary professionals and agrovets were unaware of any specific guidelines for antimicrobial prescription or sale, which also extended to sale and use of HPCIAs. Some veterinary professionals cited guidelines from the Kenya Veterinary Board (21.4%) or instructions from the County Veterinary Officer (10.7%) regarding sales or use of antimicrobials. Agrovet staff cited pharmaceutical guidelines (6.1%) or Kenya Veterinary Board guidelines (14.3%).

In terms of defined AMR, there were no confirmed instances due to no formal diagnostics being undertaken. However, few instances of clinical failure were reported by agrovet staff (by proxy of farmers returning to purchase an alternative antimicrobial from them). Where clinical failure was reported, reported failures were to oxytetracyclines (10.2%), penicillin-streptomycin (4.1%), and sulfonamides (8.1%). The majority of agrovets indicated that they "[did] not know" or there was "no reported" resistance to antimicrobials (61.2%). Some stated that there had been cases of suspected clinical failure attributed to AMR, but they did not know to which antimicrobial (16.3%), and this was not verified in a laboratory setting. Veterinary professionals suggested that some clinical failures may be attributed to AMR, and that such failures occurred in oxytetracycline (41.4%) and penicillin-streptomycin (27.6%), but not to sulfonamides. Farmers suggested that they had encountered treatment failure in less than half of cases (41.3%). Of those who reported failure, oxytetracycline was

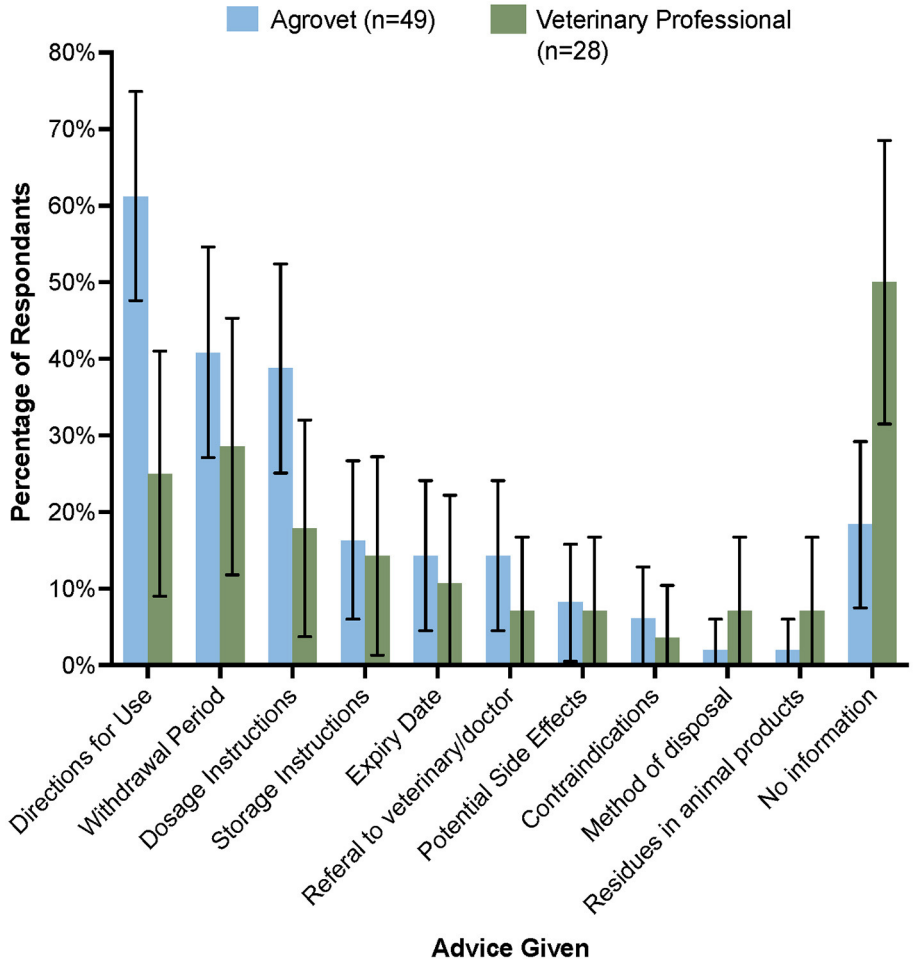

FIGURE 3 | Information given to farmers regarding AMU, AMR, and withdrawal periods at point-of-sale (agrovet shop) or when receiving a prescription (veterinary professional). Error bars represent 95% confidence interval.

the most common (20.6%), followed by penicillin-streptomycin (7.9%), and sulfonamides (1.6%). A small subgroup of farmers suggested that there had been failure but were unsure to which antimicrobial (11.1%).

Where there was treatment failure, approximately half of veterinary professionals reportedly collected a venous blood smear (53.6%) or sent blood for a bacterial culture (7.1%), or PCR (3.6%). The remainder prescribed an alternative antimicrobial without conducting diagnostics. A quarter of agrovet staff involved a more experienced agrovet staff member or veterinary professional, or the owner of an agrovet shop (28.6%) where they received a report of treatment failure. More than a quarter (26.5%) would suggest an alternative antimicrobial without gaining more information regarding the animal and 22.4% had not encountered treatment failure before. The remainder of agrovet staff would first try to obtain more information i.e., ask about more clinical signs, and then recommend an alternative antimicrobial.

Many antimicrobials prescribers/sellers (64.3% of veterinary professionals and 71.4% of agrovet shops) kept some form of records regarding antimicrobial sale or prescription or incidence of treatment failure. There was good concordance between antimicrobials volunteered as regular purchases or prescriptions and those records that we read. Half of farmers (50.0%) also had some records of antimicrobials they administered to their animals though these were often non-specific i.e., did not often contain specific antimicrobial names or dosages. When questioned, farmers were often unsure which antimicrobials were used as a veterinary professional had provided and administered the treatment, and not recorded it for them (corroborating the previous point that veterinary professionals do not provide detailed information regarding antimicrobials to farmers).

DISCUSSION

Our study has shown that all interviewed farmers and veterinary professionals in Busia county accessed veterinary antimicrobials through agrovet shops and that there were, in practice, no restrictions on class or quantity that could be purchased. The most commonly purchased veterinary antimicrobials were tetracyclines, sulfonamides and penicillins. This study

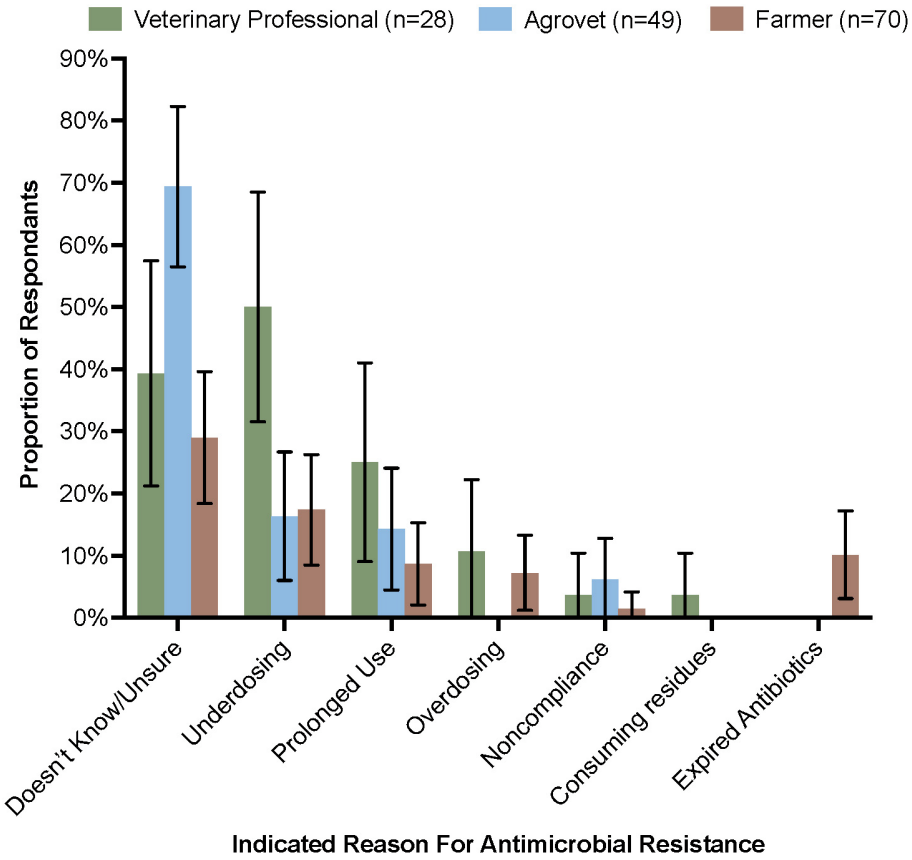

FIGURE 4 | Most common responses given by participants indicating what they thought were the main causes of antimicrobial resistance. Error bars are 95% CI.

found no reported use of fluoroquinolones or 3rd+generation cephalosporins, and only one reported use of colistin; given that these antimicrobials are critically important for human health (9, 28) this was a positive finding. However, few veterinary professionals or agrovet staff recognized examples of HPCIAs despite being presented with a list of those antimicrobials—this is likely due to lack of awareness and available information. Interestingly, these drugs are widely available and found to be drugs of choice amongst some farmers in more urbanized areas of Kenya (7), despite their relatively higher cost.

Our study highlighted a number of poor antimicrobial-related sale practices in agrovet shops, notably the dispensing of antimicrobials without a prescription and the inclusion of customer preference as a primary consideration when selling antimicrobials. Approximately 40% of agrovet staff stated that they dispensed antimicrobials without a valid prescription, though direct observations made during the study suggested that all shops sold antimicrobials without a prescription at least occasionally; this is consistent with similar studies conducted in Nairobi (23) and Tanzania (29). Indeed, observations made during the study also suggest that there is a lack of formal written prescriptions, and that most prescriptions are simply verbal instructions from a veterinary or veterinary paraprofessional. However, this is potentially for convenience, where travel to an agrovet shop or a veterinary professional cannot travel, or a farmer cannot afford to pay for an in-person visit, to a farm. Furthermore, there were significant inconsistencies in the reported use of antimicrobials. Despite not being prescribed or sold as such, antimicrobials we suggest that antimicrobials were used for prophylaxis and/or growth promotion based on participant responses.

In our study, cost of antimicrobials to farmers was a major consideration—we noted that oxytetracyclines were on average cheaper than penicillin-streptomycin (relative to number of doses per container), but more expensive than sulfonamides when adjusted for cost per dose (**Figure 2**). To save on costs, farmers, who in this study represent a low income group (30) sometimes opted to bypass veterinary professionals when treating their animals. Numerous farmers stated that they had reused prescriptions from a previous encounter with a veterinary professional or agrovet staff, or they opted to use leftover antimicrobials from previous treatment because they had previously worked. To prevent such irrational drug use by farmers, 75% of veterinary professionals purposely did not provide any direction for AMU to farmers so that full responsibility for treating animals remained with

them (**Figure 3**). Farmer administration of drugs would be difficult to control; this would require interventions that limit access to antimicrobials (31) but also would require regulation of pricing structures for access to veterinary care, which might be challenging in a liberalized veterinary market (32).

One of the major drivers of AMU is commercial gain. Livestock production is an important industry in developing countries, driven by market demand and financial incentives. As such, farmers need to keep their animals healthy and resort to this by using antimicrobials. In Kenya, antimicrobials are viewed as high-margin products that are typically administered or sold by a recognized professional. Agrovet staff are routinely approached by large pharmaceutical companies to train staff (**Table 1**) regarding specific antimicrobials they are selling and encourage them to purchase stock for their shops. As staff have made an investment, they would therefore preferentially sell these antimicrobials, even in instances where a cheaper antimicrobial may be more appropriate. It is a lucrative business, as is testament to the large number of agrovet shops and informal veterinary antimicrobial sellers found within this KAP study. Separately, veterinary professionals are paid a salary and would make additional money through extension services, such as selling antimicrobials directly to a farmer, and then charging them for administering those antimicrobials (and taking responsibility for treatment and follow-up care of those animals). Where farmers may be unable to afford such services, they would resort to noting what the veterinary professional had done, and attempt to replicate this later, by purchasing antimicrobials without a prescription.

Few studies have focussed on antimicrobial prescribers and sellers and their knowledge of AMR in LMICs (33). In this study there was mostly superficial knowledge of AMR and the dangers of AMU amongst farmers, agrovet staff, and some veterinary professionals (**Figure 4**). This may have been due to specific terminology, as other studies have highlighted that there is minimal familiarity with terms such as AMR and antibiotic resistance (34, 35). After an accurate definition was provided, some interview participants were able to correctly give examples of factors which they thought may contribute to the emergence of AMR. Withdrawal periods were also generally not well-understood or abided by. A study conducted in neighboring Tanzania found that depending on the region, people were variably likely to observe withdrawal periods (36), highlighting different attitudes to AMR amongst people engaged in different types of agriculture. If there is insufficient knowledge of the contribution of antimicrobial residues, this may indicate why. Some farmers in our study suggested that withdrawal periods only applied to milk or eggs and were unaware that residues may also occur in meat. There is clear scope, in line with Kenya's National AMR Action Plan, to improve knowledge of livestock keepers and address the poor understanding of rational drug use amongst farmers and antimicrobial sellers; innovative approaches such as information design (which delivers relevant information in an accessible way to the end user) (37) could play a role in communicating information regarding AMR in appropriate and simple ways.

An important issue identified in this study was ambiguity surrounding AMR. As there is a routine lack of diagnostics undertaken, cases of treatment failure may be attributed to use of incorrect antimicrobials or incorrect dosing, rather than development of AMR. Veterinary professionals typically relied on their clinical experience for disease identification, and agrovet staff relied on farmer description of animal disease, or more experienced agrovet staff to advise on an appropriate treatment for those reported signs. Several diagnostic laboratories exist in western Kenya, though the cost involved in collecting samples, shipping them to a laboratory and the testing itself is a barrier to most farmers, who cannot afford such services. As such, there is over-reliance on empirical, broad-spectrum antimicrobials.

Because AMR surveillance has not been systematically conducted in Kenya, there is incomplete data regarding the prevalence of AMR and AMU. Whilst other studies have shown a high prevalence of AMR amongst humans and livestock in other LMICs (38, 39), there is a paucity of data in Kenya. Absence of documentation regarding veterinary antimicrobial therapies, systematic reporting of treatment failures, and AMR surveillance, precludes gaining an accurate representation of issues surrounding AMR in the current circumstances.

There are complex factors at play surrounding antimicrobial prescription, including high public demand for access to antimicrobials. We suggest that several behavioral interventions in tandem with legislative or policy reforms implemented to agrovet, and veterinary professional staff may reduce inappropriate prescription. We suggest three major interventions: (1) Detailed guidance on alternative, non-antimicrobial therapies could be delivered to agrovet shops from local government. In instances where a diagnosis is made by a veterinary professional, consultation of documentation may suggest that an antimicrobial is not generally indicated for that diagnosis and several alternatives may be suggested. (2) Specific justification for prescription of antimicrobials. Where an agrovet or veterinary professional prescribes an antimicrobial, they must explicitly justify why this was necessary and why an alternative therapy could not be used. Previous studies have found that staff accountability significantly improves decision making accuracy (40). (3) Ranking of veterinary professionals and agrovets. Each sub-county in Busia tracks the number of agrovet shops and registered veterinary professionals; these staff could be ranked depending on the number of inappropriate prescriptions that have been made and sent an email or text message informing them on their prescribing rates, compared to others. Peer comparison is a strong driver of performance and may help to keep inappropriate prescription low, as has been studied in clinical settings elsewhere (41). Concurrently implementing these interventions may significantly reduce the number of antimicrobials prescribed, whilst also maintaining a high standard of care expected from farmers treating their animals. Finally, to reiterate the relevance of antimicrobial stewardship training, studies have shown that in major national referral and teaching hospitals in Kenya, fewer than 15% of clinicians had received substantial lectures on antimicrobial stewardship and AMR during their training (42). Reform of veterinary and medical certificates, diplomas, and undergraduate

training, as well as continuing professional development should be made to better equip veterinary professionals to deal with AMU, AMR, and antimicrobial stewardship. Such interventions could be implemented with ease via the rollout of the new national action plan on prevention and containment of AMR, being managed by the Fleming Fund (https://www.flemingfund.org/wp-content/uploads/0cff5e08e6a64fcf93731d725b04792e.pdf).

This study determined that community-owned agrovet shops are the primary level of veterinary care in an area of smallholder crop-livestock farming. Previous studies have shown positive correlations between AMU and the level of AMR in animal populations (43, 44), and therefore, use of antimicrobials in this smallholder farming production may constitute a major contributing factor to the development of AMR. To remedy this, antimicrobial stewardship must be foremost for prescribers and sellers. As well as improving knowledge in the retail and farming sectors, efforts should be made to standardize record-keeping into a computerized system managed in collaboration with local government, to allow for accurate tracking of prescribed and sold antimicrobials and minimize over- and non-prudent use of antimicrobials, whilst factoring in perceived interventions.

CONCLUSIONS

The findings presented in this study suggest that there was low awareness of both AMU and AMR amongst both antimicrobial users and prescribers, which can have significant public health implications. High rates of AMU (and subsequently AMR) will eventually lead to a situations where there is significantly reduced antimicrobial efficacy in both veterinary and human medicine. In particular, inappropriate prescribing practices by agrovet shops highlights the need to encourage diverse forms of targeted education and behavioral interventions, focused on prudent antimicrobial prescription and use, in combination with the deployment of national level AMR surveillance in both the livestock and human populations utilizing an inter-sectoral collaborative approach to restrict the inappropriate use of antimicrobials. Ongoing monitoring and surveillance of AMU is challenging in LMICs, but crucial in understanding how, and which, interventions can be implemented with limited resources. Reform via implementation of the suggested behavioral changes, as well engaging with policymakers and legislative bodies, and intersectoral support between veterinary and human medical staff will be key factors in reducing inappropriate prescription of antimicrobials.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are publicly available. Participant response data (minus potentially identifiable data such as location and region) collected as part of this study has been deposited on GitHub (https://github.com/Steven-Kemp/Kenya_KAP).

ETHICS STATEMENT

The animal study and studies involving human participants were reviewed and approved by Institutional Research Ethics Committee of the International Livestock Research Institute (ILRI-IREC2016-03) and University of Liverpool Veterinary Science Research Ethics Committee (VREC387). Written informed consent was obtained from the owners for the participation of their animals in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

SK: conducted fieldwork, assessed participant responses, and characterized them into distinct themes. SK, NW, EF, and GP: conceived study, design and implementation of questionnaires, and wrote and revised manuscript. GP: validated these themes. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fvets.2021.727365/full#supplementary-material

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"He Who Relies on His Brother's Property Dies Poor": The Complex Narratives of Livestock Care in Northern Tanzania

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Background: Endemic zoonoses have important impacts for livestock-dependent households in East Africa. In these communities, people's health and livelihoods are severely affected by livestock disease losses. Understanding how livestock keepers undertake remedial actions for livestock illness has the potential for widespread benefits such as improving health interventions. Yet, studies about livestock and human health behaviours in the global south tend to focus on individual health choices. In reality, health behaviours are complex, and not solely about individualised health experiences. Rather, they are mediated by a range of "upstream" factors (such as unequal provision of services), which are beyond the control of the individual.

Methods: This paper presents qualitative research conducted from 2014 to 2019 for a study focused on the Social, Economic, and Environmental Drivers of Zoonoses in Tanzania (SEEDZ). Qualitative data were collected via focus group discussions, community meetings, informal interviews, formal in-depth interviews, observations and surveys that addressed issues of health, disease, zoonotic disease risks, and routes for treatment across 21 villages. Thematic analysis was carried out on in-depth interviews and focus group discussions. Conceptual analyses and observations were made through application of social science theories of health.

Findings: Livestock keepers undertake a range of health seeking strategies loosely categorised around self and formal treatment. Two key themes emerged that are central to why people make the decisions they do: access to resources and trust in health care providers. These two issues affect individual sense of agency which impacts their ability to act to improve livestock health outcomes. We suggest that individual choice and agency in veterinary health seeking decisions are only beneficial if health systems can offer adequate care and health equity is addressed.

Significance: This study demonstrates the value of in-depth qualitative research which reveals the nuance and complexity of people's decisions around livestock health. Most importantly, it explains why "better" knowledge does not always translate into "better" practise. The paper suggests that acknowledging and addressing these aspects of veterinary health seeking will lead to more effective provision.

Keywords: health seeking behaviours, One Health, livestock health, KAP, East Africa

INTRODUCTION AND BACKGROUND

Across Africa, over 70% of people rely on livestock for their livelihoods (1). Within East Africa, the reliance on livestock translates into multiple forms of livestock-based livelihoods such as pastoralism, agro-pastoralism, and small-scale farming (2). Sixty percent of rural households in Tanzania derive income from livestock which comprises 22% of total household income (3). Yet, livestock face numerous health challenges including, but not limited to endemic zoonoses such as brucellosis, Q-fever, Rift Valley fever, and anthrax. These diseases can threaten livestock-based livelihoods by directly affecting human and animal health (4, 5) and also indirectly through livestock production losses (6). Thus, there are linkages between human, animal, and environmental health, commonly referred to as One Health, which framed this research. As studies of One Health have shown, the health and well-being of one's livestock have broader socio-cultural impacts connected to human health and well-being as well (7, 8).

The issue is further compounded by limited access to formal human and livestock health care in remote rural communities (9) as well as by other livelihood and infrastructural constraints (10–12). These factors cause disproportionate economic and social burdens on the rural poor, leaving them and their livestock more vulnerable to disease (4, 13, 14). Livestock keepers in Arusha and Manyara Regions of northern Tanzania often have to make difficult decisions within a veterinary health system which imposes limitations on the treatment options available to livestock keepers. As presented in detail below, both health systems in Tanzania are shaped by health policies that stipulate public-private partnerships, with overstretched state services, and a lack of private service to fill the gaps (15). This is reflective of similar health constraints faced by the rural poor across the globe (16). Thus, understanding the impeding factors and pathways taken by livestock keepers for livestock care (including for ill health caused by zoonoses) is key to safeguarding human health, in addition to designing effective policy and disease management support.

Attempts to understand health behaviours often draw on measuring levels of knowledge, awareness, practises and beliefs in relation to a particular health issue. "Health seeking behaviour" (HSB) studies for example are used to describe why, when and how individuals, social groups and communities seek access to health care services (17, 18). They achieve this by following the sequence of remedial actions undertaken for illness, from the recognition of symptoms through different types of help seeking until they feel healed or capable of living with their condition (17). Studies on health seeking behaviours overwhelmingly relate to human health, and most conceptual frameworks seeking to explain health behaviour and access to care directly relate to human experiences and their choices [see for example Muela et al. (19) and Obrist et al. (17)]. Studies on animal health seeking behaviours similarly focus on individual human decisions and actions taken to manage animal ill health [see Awosanya and Akande (20); G/hiwot et al. (21)]. Understanding how people seek healthcare for their livestock has important implications for human health (e.g., in the case of zoonoses), for human livelihoods, as well as in demonstrating the intricate social and cultural connectivity between animals and humans.

The comon issue in the application of both animal and human health seeking is the tendency to focus attention on the individual decision-maker (22) with less consideration of the systemic constraints which may impact their health decisions. For instance, many interdisciplinary studies of health in the global south rely on knowledge, attitude, and practise (KAP) surveys [sometimes referred to as knowledge, attitude, behaviour, and practise (KABP) surveys] (23, 24). KAP studies are commonly utilised in interdisciplinary approaches to understand complex systems, and often aim to collect quick "qualitative context" through interviews or focus group discussions [see Caudell et al. (9)]. However, while offering important insights into a particular health issue, this often happens at the expense of long term, in-depth understanding about wider social and cultural factors that both constrain or enable individual action. This point has been most powerfully made in Farmer's (25) influential work on Tuberculosis and HIV/AIDS:

> The countless Knowledge, Attitudes, and Practises surveys and AIDS educational interventions derived from them have not achieved their aim, and to say so *is not to object to* AIDS *education* [. . .] But show us the data to suggest that, in settings where social conditions determine risk for HIV infection, cognitive exercises can fundamentally alter risk. We know that risk of acquiring HIV does not depend on knowledge of how the virus is transmitted, but rather on the freedom to make decisions. Poverty is the great limiting factor of freedom. [(25), p. 40, emphasis added]

As Farmer suggests, the ability to make "appropriate" decisions around health does not solely depend on knowledge, but also on individual ability (or agency) to make choices within enabling or constraining contexts in which people live. Poverty is the greatest limiting factor for agency, but it is far from the only one. Studies that are predicated on identifying discrete variables (or individual actions) that can be pinpointed for "risk reduction,"

"awareness raising," or "knowledge building" (26) can result in a "straightjacket" that leads to a "narrowing of the social world" [(14), p. 14] thus missing the hetereogeneity in which health, and social life more broadly, occurs [see also Bardosh (27), for mixed methods approaches to study about NTDs that expand beyond KAP]. Without an understanding of the sociopolitical contexts within which individuals make decisions (28), and particularly health decisions, and indeed veterinary health decisions, there is a danger that HSB studies, and KAP studies as an example of these, overemphasise the *agency* of individuals to act as capable and rational actors while ignoring the ways contextual issues and systemic barriers influence individual health, health related behaviours, and broader access to care (25). Individual actions, "rational" economic behaviours and decisions thus become the focus for health interventions and health actions (25, 29) which can subsequently lead to a belief that people are behaving "irrationally" when they do not follow "expected" behavioural norms. This is true for both human and veterinary health. As Parker et al. (30) contend that key insights about how people experience health and illness are only gained through longer periods of time and investment in ethnographic engagements which in turn affects broader debates about and investments in health.

Drawing on in-depth qualitative data from Tanzania about health, health seeking behaviours, and care for livestock, this paper seeks to go beyond a traditional KAP study to reveal how "everyday" experiences of livestock health are structured not only by individual behaviours and preferences but also by key structural factors, including systemic health inequities[1] and challenges within veterinary health systems. Understanding these wider, contextual factors can reveal the reasons why better knowledge or attitudes towards risk may not lead to changed practise because the individual is not able to change the conditions that constrain their actions (as the HIV/AIDS example above provides). The paper will contextualise the strategies adopted by livestock keepers to manage the health of their livestock thus providing a deeper understanding of factors influencing veterinary based health seeking behaviours.

Tanzanian Health Landscape (Human and Veterinary)

The structures of both the human and veterinary health system in Tanzania, established at independence in 1964 under the "African socialist" reforms of the Nyerere presidency (1964–1985) form a strong edifice from which care is organised in the country. This underlying structure was based on centralised government authority with district intermediaries who supervised field extension services in rural communities, budgeted by national health and veterinary ministries (see **Figure 1**). While the basic frameworks (and underlying bureaucracies of management) were established during the post-independence socialist period, the ensuing Structural Adjustment era in the 1980s (spearheaded by the International Monetary Fund) led to substantial changes in the delivery of livestock and human health in Tanzania. This primarily included: decentralisation of government authorities, defunding of public services, and the increasing privatisation of health provision (yet with limited capacity to increase private services) (32, 33). The veterinary health system parallels the human health system but has been subject to even greater privatisation. This is evidenced through the emphasis of public-private partnerships for meeting veterinary health needs in the most recent livestock policies (34). With government services particularly underfunded (33) and the private sector lacking in service providers, the veterinary health system has left rural areas largely underserved (35). In these areas, the number of livestock greatly outstrips the capacity of the health providers available (33). For example, within Ngorongoro District, an area with high livestock density, 73% of pastoralists reported having no access to extension services (33) (which includes basic animal health services). Thus, the current system often falls short of meeting local human or veterinary health needs, with public provision of veterinary care in particular facing striking disadvantages for meeting broad scale animal health needs (36).

As a result, there are numerous challenges in providing adequate health services when livestock are ill, or in providing sufficient health information for prevention measures. There are also significant challenges for livestock keepers in accessing services when they are available. This is especially salient for rural livestock keepers who live in complex environments with increasing pressures from large scale land use change and climate change or conversion of grazing lands to farms or conservation areas (11, 37–41). This is further compounded by conflicting expectations of both government and citizens about who has the key responsibilities for service provision, including for vaccination against endemic and epidemic diseases [see United Republic of Tanzania (URT) Livestock Policy (34)]. There is also a long and complex history of neglect from and mistrust of available veterinary systems and experts spanning back first to colonial regimes, through the post-independence, socialist based system, and lasting into present day (8).

Within the structure of the veterinary system, uneven access to government services (for which most rural livestock keeping communities rely upon) exists depending on the type of livestock keeping system. For example, it is common practise in Tanzania for there to be one livestock field officer (LFO) per ward regardless of the number of livestock living in that ward[2]. Thus, smallholders, who keep far fewer animals than pastoralists, and in geographically smaller villages often have easier access to service providers and veterinary supplies due to closer proximity. Rural infrastructure (including roads, cellular service, water supplies, schools) tends to be poorer in districts where pastoralists reside (42). In the absence of access to government *or* private livestock health services, livestock keepers are often left with no choice but to manage livestock disease completely on their own, sometimes

[1]We specifically refer to "health inequity" rather than "health inequality." The former denotes an unjust and unfair distribution of health risks and resources, whereas the latter refers to any measurable aspect of health that varies across individuals or social groups. Health inequality is absent from moral judgement on whether the differences are fair or just (31).

[2]Wards are administrative units, smaller than districts and larger than villages. Wards are often comprised of 3–5 villages, which are based on human population.

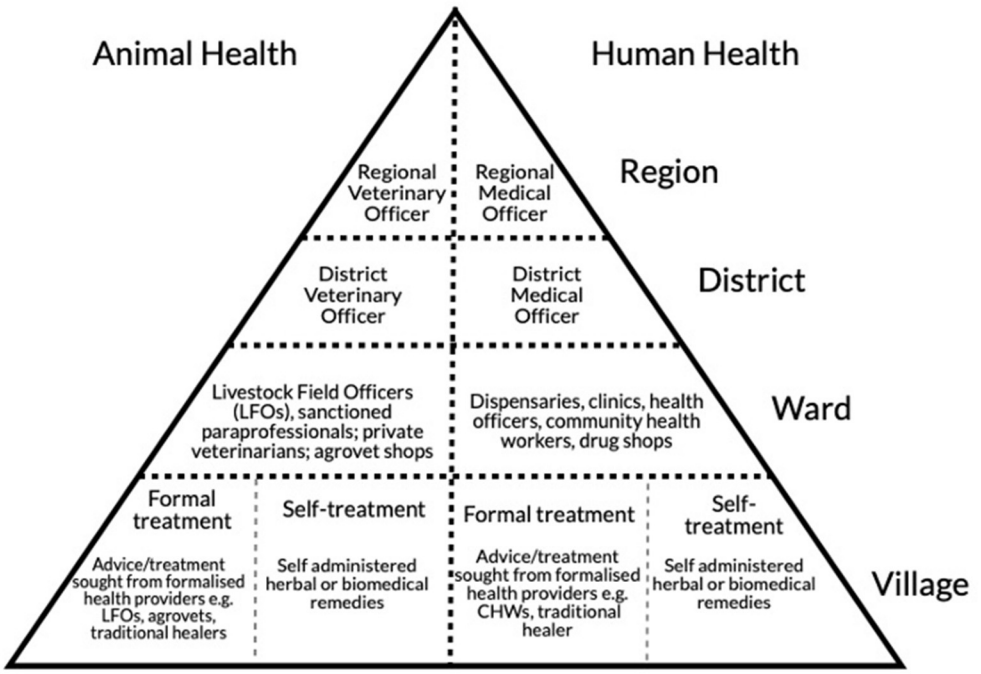

FIGURE 1 | Tanzanian veterinary and human health system structure. The country is divided into distinct administrative units, with the Region being the largest. Each Region is comprised of up to 7 Districts. District health administration includes a formal District Veterinary Officer (DVO), and District Medical Officer (DMO) who are trained degree holding professionals and who lead a team of district [(para)veterinary and medical] officers. Wards are administrative units that encompass 2–6 villages, with each ward or village acting as the central location for extension services: for example veterinary, agricultural, and medical. Ward officers for veterinary health include Livestock Field Officers (LFOs) who are trained (at certificate level or higher) in livestock health, livestock production, range management and who serve multiple villages. Ward officers for human health include clinical officers (who work in dispensaries and throughout the health system), technicians, and community health workers.

with little to no advice much less direct hands-on evaluation available and with varying conceptions of self "expertise" (43).

In order to understand how livestock keepers manage animal ill health in light of varying provision of and access to services, it is important to map the range of options that livestock keepers have within the Tanzanian veterinary health system. The very real set of constraints and challenges within the system affects how people make decisions about the care for their animals. What emerges is a range of veterinary care and health seeking behaviours (HSB) that highlight the ways in which livestock keepers mediate that veterinary care. These HSB span from self-reliance for treatment, i.e., "self-treatment" to utilisation of diagnostic based care offered by trained private or public veterinary practitioners. Both formal and informal health care options exist within this suite of HSB. In practise, these are often utilised simultaneously as there are not simple choices of "formal" vs. "informal" nor "self-treatment" vs. supervised care. Furthermore, these options are not mutually exclusive or exclusionary. For example, and as our data will show below, in the case of agrovets a livestock keeper may purchase drugs based on personal prior experience and ethnoveterinary knowledge *or* may ask the seller for advice and guidance. Similarly, LFOs may be consulted for advice via phone or be called out to examine a sick animal (but, as our data will show, usually as a last resort). Thus, while we present the typical binary framework of care, we also point to the messy reality and strategic practise that often occurs in daily life (**Table 1**). An outline of animal health providers and their roles is provided in **Table 2**.

METHODS

This paper presents data from the "Social, Environmental and Economic Drivers of Zoonotic disease" (SEEDZ) project conducted in northern Tanzania from 2015 to 2019. SEEDZ data collection included a large cross-sectional study of human and livestock zoonotic disease risk in 21 villages across ten districts in two regions of northern Tanzania (Arusha and Manyara) in an area of 66,461 km^2 and within semi-arid and sub-tropical agro-ecological zones (49). The two regions have a population of 3.1 million people and ∼16% of all cattle and 26% of all sheep and goats in Tanzania (50, 51). Social science data collection was built into the cross-sectional design and included mixed qualitative and quantitative tools applied at community and household levels. A detailed overview of the cross-sectional study design and methods can be found in Ahmed et al. (6) and de Glanville et al. (2).

Site Selection

Villages were stratified based on primary livelihood activity and included pastoralist communities, dominated by transhumant

TABLE 1 | Typical types of treatment options are often categorised as "self-treatment" or reliance on more "formal" treatment channels (biomedical here refers to treatment options based in the formal (western) scientific tradition, whereas local refers to informal, local, traditional, or management based ethnoveterinary treatments).

Types of treatment options			
Self-treatment		**Formal**	
Biomedical	Agrovet shop (drugs bought based on experience)	Biomedical	Agrovet shop (advice sought from formally trained seller)
	Market drug sellers		
	Advice (from social network or animal health providers)		Evaluation/assessment from LFO or DVO
	Self (based on past experience)		
			Evaluation/assessment from private vet or paraprofessional (including informal providers, such as CAWHs)
			Regional vet testing facilities
Local practises	Use of local herbs or remedie	Local practises	Local herbalists, healers
	Behavioural/management strategies		Local experts in birthing

Importantly, we include herbal and traditional healers as "formal" options as, although they are not government sanctioned or trained with biomedical credentials, they are widely recognised among livestock keepers as formalised providers of treatment and advice [see Langwick (44) for further discussion on the regional importance and legitimacy of traditional healers for therapeutic interventions]. Health seeking pathways often begin with self-treatment and may end up with individuals seeking formal treatment if the problem persists or escalates to an unmanageable level. Simultaneous use of treatment options also commonly occurs.

TABLE 2 | Categorisation of formal and informal animal health service providers in Tanzania [adapted from Virhia (45)].

"Expert"	Definition
Veterinarians (public and/or private)	Individuals who hold a degree in veterinary medicine or its equivalent from a veterinary institution recognised by the veterinary statutory body (The Veterinary Council of Tanzania) (46)
Veterinary Paraprofessional (VPP)	Individuals who have received formal training at diploma level in animal health level from training institutions accredited by the appropriate government agency or the veterinary statutory body and the activities that they are permitted to conduct will reflect their level of formal training (47)
Veterinary Paraprofessional Assistant (VPPA)	Individuals who have received training at certificate level in animal health from training institutions accredited by the appropriate government agency or the veterinary statutory body and the activities that they are permitted to conduct will reflect their level of formal training (47)
Community Animal Health Workers (CAWH)	CAHWs can be considered as distinct from VPPs/VPPAs as they generally do not have a certificate from a government accredited training institution. They are mainly livestock keepers who are nominated by the community and trained (by government officials, NGOs or farmer organisations) in basic animal health techniques (such as vaccination and deworming for instance) and who deliver a limited range of veterinary services to their communities.
Livestock Field Officers (LFO)	Individuals appointed by the government to provide livestock extension and advisory services at the village or ward level. LFOs should receive formal training at either the diploma or certificate level in animal production and range management from training institutions accredited by the appropriate government agency.
Local experts	Those without any government recognised qualifications but are known by others in their community as having knowledge through experience.
Agrovets	A supply store for farmers selling veterinary products (including medications, animal feed, supplements pesticides, vaccinations) and agricultural products (including seed, fertilisers and herbicides). Individuals working in agrovets are often viewed as a source of knowledge and advice on livestock and agricultural issues. Agrovets may sometimes be owned and run by LFOs.
Traditional healers	An umbrella term used to describe healers who call upon divination and spirituality among other remedies to solve disequilibrium among afflicted individuals (48).
Situational experts	Those who have knowledge about particular animal health issues such as birthing, or specific diseases.

livestock production, and "mixed" communities that practise both livestock production and crop farming [see de Glanville et al. (2)].

The categorisation of villages was carried out with district administrators [e.g., District Veterinary Officers (DVOs)] and 11 pastoralist and nine "mixed" villages were selected, with one periurban "mixed" village on the outskirts of Arusha city selected for piloting the study. All villages were included in data analysis as methods were not modified after piloting. Areas for household sampling were determined in agreement with village authorities by random selection of 2–3 sub-villages (administrative units that divide villages, with an average village having 3–5 sub-villages). See **Figure 2** for a map of the study regions and villages.

Quantitative and Qualitative Data Collection

To maintain our long-term relationships with communities, our data collection built on previous studies conducted by the researchers on the causes of fever in the region and included several overlapping villages. Further, we contribute detailed ethnographic experience in the study area based on the authors' individual research in the country on a host of health and non-health related issues (totalling over 20 years).

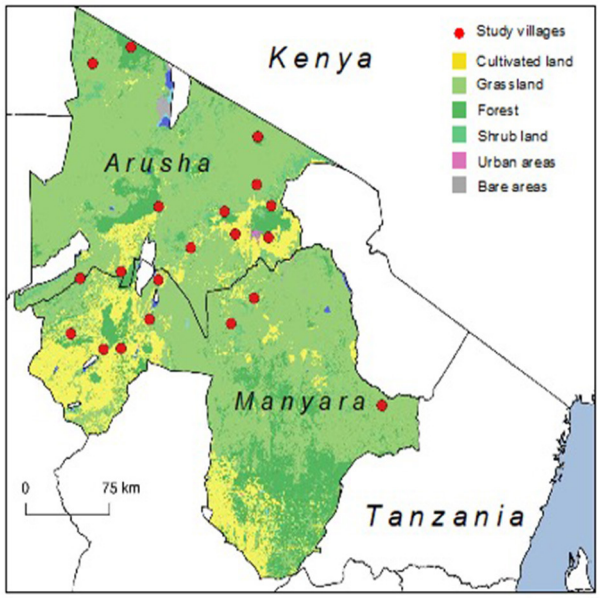

FIGURE 2 | Map of study regions and villages in northern Tanzania. Land classifications denoted in Arusha and Manyara Regions [from de Glanville et al. (2)].

Thus, data collection tools and qualitative data particularly, is couched in long-term ethnographic study in the country. Household questionnaires were broad surveys that included information on household demographics, economics, livestock management, and livestock health. They also included questions about household decision-making, gender roles around livestock management, and zoonotic disease awareness. Qualitative data collection was carried out in each sub-village using focus group discussions (FGDs) (average of 10–15 participants each) and in-depth, semi-structured interviews (IDI) (see **Table 3**) wherein participants and researchers were provided space to answer freely, open ended questions with on-the-fly follow-up questions asked as the conversation dictated. Key members of each community were identified via village officials (such as village chairpersons and executive officers) and were invited to participate. They included: village leaders (governmental, traditional and women's leaders), and widely respected members of the community. IDIs also included local health (veterinary and human) providers. FGDs were overwhelmingly gender segregated (with only seven mixed groups out of 57 FGDs) in order to provide women space to speak freely amongst their peers, a common practise in patriarchally dominated communities. Follow up interviews were conducted in a selection of eight villages between July and October 2018 to further explore health seeking behaviours for livestock and human illness. These were selected opportunistically from previous surveys or in-depth interview participants and based on field team capacity and budget and the respondent's time availability and willingness to talk to us again. Interviews were audio recorded (when consented to by participants), transcribed and translated from Swahili or local language (primarily Maasai and Iraqw languages) into English by project research assistants. Any discrepancies in translation were minimised through continued discussion with translators and alignment of vocabulary and commonly used terms. Translators were often the same field team members conducting the interviews or participating in broader data collection, thus had a familiarity with interview questions, cultural and language contexts, and commonly used terminology. We also made repeat visits for follow up interviews to a selection of interviewees to build trust in communities, verify data and for data triangulation. Where interviews were not audio recorded, in-depth handwritten notes were taken by a dedicated note taker and typed for translation and analysis. All materials were stored as password protected files and secured as per University of Glasgow and the National Institute of Medical Research in Tanzania ethical approvals (see below for details). Personal or identifying information such as names were removed from all transcripts. All identifiers, including village names, were removed for presentation in the findings below.

Analysis

Qualitative analysis was conducted using NVivo^{TM} (version 12) ethnographic software (QSR International) and by combining inductive and deductive thematic analyses (52, 53). We created a coding framework based on interview questions which focused on actions taken in response to livestock ill health and livestock disease risks. After an initial reading of the interviews, iterative codes were then added as emergent themes arose. Coding was conducted by three of the authors (AD, JV, and JS) with regular cross checking, double coding, and discussion for consistency, concurrence and agreement. Key themes included summary descriptors of participants health seeking behaviour, which we categorised into "self" treatment or "formal" treatment. A quantified summary of key themes relevant to this paper was deduced after several rounds of thematic coding (see **Table 4**). We further categorised emergent HSB into themes that described underlying patterns of sentiment, behaviour, and experience. Further analysis of descriptive themes, when examined with broader socio-political contexts, revealed underlying motivations or influences to HSB and include aspects of agency, access, and trust, and are presented in the discussion.

Role of the Funding Source

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Ethics Statement

All participants provided written informed consent. The protocols, questionnaire tools and consent and assent

TABLE 3 | Qualitative interviews conducted across study sites.

Interview type	No. villages	Pastoral	Agro-pastoral	No. interviews	Total participants
Focus group discussion (FGD)	21	12	9	57	575*
In-depth interview (IDI)	21	12	9	35	35
Follow on (FO)	8	6	2	58	58

**numbers are an estimation as there was often a flow of people in and out of interviews given they were often in outdoor public meeting areas with people leaving early or joining late. Average interview size was 10 participants. Verbal consent was given for any participant joining.*

TABLE 4 | HSB decision narratives demonstrating (1) the causal factors leading to specific health decisions, (2) the subsequent health seeking actions (and their variants) and (3) the key contextual factors which influence health decisions.

Health seeking behaviours: possible decision narratives		
Causal factor leading to decision	**Actions and variants**	**Contextual influences**
Self-treatment HSB		
Sick livestock	• Self-diagnosis based on observation of livestock behaviour and clinical signs • Identification of known diseases	• Indigenous livestock breed • Familiarity of disease • Funds available
Biomedical preference	• Use of drugs known to be effective through purchase or stocks kept at home • "Trial and error" use of drugs kept at home • Agrovet: buying medication and self-administering to livestock • Calling other expert or social network for advice on diagnosis or drug use	• Advice from agrovets, livestock officers and social network • Past experience with positive outcome of specific drugs • Funds available
Local healing preference	• Collecting herbs, used for known diseases/symptoms • Herd management	• Local remedies known and used, but scepticism over effectiveness • Familiarity with disease/ailment • Familiarity with effectiveness of treatment
Formal treatment HSB		
Sick livestock	• Drawing on formal sources of advice from trusted expert	• Condition persists or worsens (*after* self-treatment)
Biomedical preference	• Calling the LFO • Calling a private vet or paraprofessional when selftreatment options exhausted • Agrovet: asking trained veterinary agrovet for advice on diagnosis/treatment options • Calling "non officially recognised" paraprofessionals such as CAHWs	• Exotic breed • For specific conditions (anthrax, black quarter) • For unfamiliar symptoms/ disease • During disease outbreak / vaccination
Local healing preference	• Calling in traditional healer or herbal expert	• Belief in traditional practises • Cost

Causal factors initiate the need to seek remedial actions (i.e., a sick animal) and personal preference dictates whether biomedical or lay treatments will be chosen in the first instance. Choice is also heavily determined by contextual influences, such as prior experiences, familiarity, availability of providers, beliefs and breed of livestock which further highlight the complexity of factors that lead to certain health decisions.

procedures were approved by the ethics review committees of the Kilimanjaro Christian Medical Centre (KCMC/832) and National Institute of Medical Research (NIMR/2028) in Tanzania, and in the UK by the ethics review committee of the College of Medical, Veterinary and Life Sciences at the University of Glasgow (39a/15). Approval for study activities for each researcher was also provided by the Tanzanian Commission for Science and Technology (COSTECH) and by the Tanzanian Ministry of Livestock and Fisheries, as well as by regional, district, ward and villagelevel authorities in the study area.

FINDINGS

We present findings from a combination of data sources including FGDs, IDIs, surveys, and observations and field notes. Because of the overlapping and complex nature of the types of health seeking, we attempt to draw out subtleties through a summary of emergent themes, direct quotation from participants and ethnographic context. The first portion of the findings focuses on overall themes and trends, followed by discussion of the nuances of self-treatment (including intrinsic and extrinsic factors), and concludes with the experiences and contingencies of formalised care seeking.

Mapping the Conditions and Contradictions of Health Seeking

To summarise overall findings about health seeking behaviours for livestock illness in our study communities, we first categorised participant's HSB as either "self-treatment" or "formal" treatment. We mapped known categories (as described in **Table 1**) against findings which emerged in the data (**Tables 4**, **5**). Intrinsic factors for self-treatment options rely

TABLE 5 | Frequency table of themes in interviews.

Frequency table of health seeking behaviours				
Treatment type	**Treatment preference**	**Specific action mentioned**	**No. of FGDs theme emerged within ($n = 41$)**	**% of FGDs**
Self-treatment	Biomedical	**Drug purchase related:**		
		General self-treatment	40	98
		Buying medicines from agrovet	18	44
		Buying medicines from a market	6	15
		Information related:		
		Reliance on one's own past experience/self knowledge	32	78
		Self-treatment through a process of trial and error	21	51
		Seeking advice from one's social network	16	39
		Using preventative treatments such as dipping	17	41
	Local practises	Collecting and administering herbs/lay treatments oneself	19	46
		Using traditional herd management techniques for prevention or treatment	4	10
Formal treatment	Biomedical	Formal biomedical treatment including vaccinations or severe outbreaks	33	81
		Formal biomedical treatment excluding vaccinations or severe outbreaks*, i.e., everyday illness	18	45
		Treatment from LFO	10	24
		Treatment advice from agrovet	12	29
		Treatment *via* paraprofessional or community animal health worker (CAHWs)	7	17
	Local practises	Herbal/lay remedy expert	4	10
		Situational experts e.g., birthing	3	7

*We only included interviews that had audio recordings and English transcripts for this component of the analysis, or a total of 41 of 64 FGDs. More than one type of treatment was typical for every interview analysed and no interview mentioned <4 types of specific actions. There were 6 interviews that described only self-treatment without formal treatment, whereas there were no interviews that mentioned formal treatment without self-treatment. *Severe outbreaks refer to major disease outbreaks that span to community or broader than community wide incidence, and which often require government intervention and often lead to suspension of market activities, for example anthrax or RVF. We note that comparison should be made between formal treatment exclusive of vaccinations, to denote everyday use of formal systems.*

on one's sense of agency to treat animals themselves and include use of prior knowledge and experience, trial and error, utilising prior advice and preference for lay treatments. Extrinsic reasons include lack of access to formal services, prohibitive costs and mistrust in formal providers. In most cases, when self-treatment options are exhausted livestock keepers move onto formal treatments including seeking advice from agrovets and/or calling formal providers to come and evaluate and examine the animal as a last resort. While we initially categorised HSBs as either "formal" or "self-treatment" and "biomedical" or "local" treatment, in practise they are often in-between the two and commonly a combination of multiple options. For example, there is overlap between self-treatment and formal treatment, especially when agrovets are the primary source of advice for self-administration of treatment, as discussed above and in detail below. Moreover, we demonstrate the importance of *context* for informing health seeking practises. As the quotes below show, decisions are based on a range of interconnecting factors such as the availability of appropriate medication (the first quote) or of expert advice (the second) which we discuss in more detail throughout this section.

Q1. *RESPONDENT (R)*[3]*: It is like this, there are lots of things that we do: first when the livestock is sick we normally bring medicine home, so when it gets sick you inject it [...] and if you don't have medicine inside [your home] you grind sisal and give it to the sick livestock. Later on you go to look for medicine in the shop.*
–Men's FGD participant, Village 18, agro-pastoral

Q2. *Interviewer (I): Because the LFO does not reach this village where do you get advice on issues related to livestock management? R: It is only up to the owner because if the LFO does not come, do you wait? No, you treat your livestock (by buying medicines) the way you see it is best. There is nowhere else to seek advice.* – Men's FGD participant, Village 6, pastoral

To illustrate the importance of context we describe respondents' health seeking patterns as decision narratives (**Table 4**). This incorporates: (1) the *causal* factors leading to specific health decisions, (2) the subsequent health seeking actions (and their variants) and (3) the key contextual factors which influence health decisions. The context in which livestock

[3]Respondents (plural) are referred to as "Rs", individual respondents as "R" and Interviewer as "I" throughout. If there are multiple interview respondents they will be numbered, i.e., R1, R2.

(and human) illness occurs is key to shaping an individual's sense of agency and thus informs subsequent health seeking behaviours. To highlight the interlinked nature of health seeking - livestock keepers often seek advice from those selling drugs in agrovets, and those advisors may be formally trained experts, (para)veterinarians or community animal health workers (CAHWs) or lay shopkeepers who only sell drugs as a business with no formal veterinary credentials. Thus, HSB in one category does not preclude the other and, most commonly, HSB narratives are overlapping, multi-stepped and multi-faceted.

Table 5 presents the frequency of specific treatment actions undertaken as part of the narratives of HSB discussed in our focus group discussions ($n = 41$). Nearly all participants described using self-treatment options (98%) when asked to describe what actions they normally take in response to livestock ill health. Specific questions included some variation of: "when you see signs of previously mentioned diseases, what is the first action you take?" These self-treatment options included 43% buying their own drugs from agrovets. Follow up questions investigated processes and further steps or actions as well as why these actions were undertaken. As part of this line of discussion, questions about where information or skills were gained in their assessment were often asked. Thus, these actions were often undertaken in conjunction with 78% of respondents indicating that they gained expertise through past experience and generational links (elder-youth transmission of ethnoveterinary knowledge) in treating their own livestock. Additionally, while self-treatment involves independent diagnosis or assessment of an animal's condition and then administration of medication to sick livestock, it does not preclude drawing on advice, either from social networks or from formal veterinary health providers.

In terms of formal treatment, 81% of participants reported using formal biomedical treatment options at some point during any number of livestock illness situations they freely named. Use of formal providers was also highly conditional, that is, once "vaccination events" or "disease outbreaks" were removed from health seeking scenarios, only 45% of participants in FGDs reported accessing formal biomedical treatments for when their livestock gets sick, and this was usually after all self-treatment options were explored. People with exotic breeds commonly stated their need to get veterinary attention straight away, though our data did not disaggregate HSB based on breed.

Self-Treatment as a Complex HSB: Experience Narratives

Self-treatment encompassed an array of actions as explained in **Table 4**, ranging from intrinsic factors such as relying on own knowledge and past experience, trialling different drugs kept at home, lay practises, and seeking advice from friends, family and formal providers to extrinsic factors where ack of access to, and trust in, formal providers influenced health decisions. Other actions mentioned by a small number of participants include traditional herd management practises (such as isolating animals or preventing them from mixing with other herds) to prevent spread of diseases and buying medication from informal market sellers. These actions do not occur in isolation but rather are interwoven and repeated throughout the health seeking process, until the livestock gets better or dies. The words and experiences of the livestock keepers themselves (through our qualitative data) help create fuller HSB narratives and demonstrate the nuances and complexity of HSB practises. These are presented below.

The Self as Expert - Reliance on One's Own Knowledge and Past Experience

A sense of oneself as an expert, derived through experience in ethnoveterinary knowledge passed down through generations, provides a basis for some livestock keeper's belief in themselves as the most capable agents for providing care and treatment to their livestock. This was more commonly expressed in pastoralist study communities. However, when respondents were asked why they prefer to treat livestock themselves, many (across sites) referred to their extensive experience and knowledge in treating livestock:

> **Q3.** *R1: I was not advised by anyone, I grew up in a livestock area, mostly [with] cattle so I learned from my father [. . .] you know when you stay with the elders and do livestock activities together you get enough education.*
> *R2: Absolutely, it is truly a school and enough experience.* – FO participant 28, agro-pastoral
> ***Q4.*** *INTERVIEWER: So, you treat the livestock yourself? Rs: Yes. INTERVIEWER: So, someone came and gave you a course that treatment is done in this way? Rs: no. R1: We gave ourselves the course. INTERVIEWER: So, you have learned from each other? Rs: Yes. –Men's FGD, Village 17, agropastoral*

People explained their own observational practises and skills in tracking their animals' conditions, behaviours, and health through their daily interactions with their livestock. Where self-assessment is possible and treatment options are known, people will follow this course.

> **Q5.** *R1: What a woman can do is to tell if she has observed a certain sign in a cow, for example, if the cow has given little milk or there is some abnormality in the cow.* –Mixed FGD, Village 12, pastoral

A sense of self as an expert can lead to a variety of different health-seeking actions including trial and error with different drug treatments. Participants often had prior experience around "known" issues (such as East Coast fever) or in treating less well-known conditions, thus self-treatment often involves a process of experimentation using various drugs kept at home, or purchasing an array of drugs until one works.

> **Q6**. *R3: We treat by guessing. If you think its trypanosomiasis you inject trypanosomiasis medicine, after that you inject the medicine used for East Coast fever, if it is not responding I inject the medicine called Berelin,*[4] *later on if the livestock is not responding it can die or with God's grace it can recover.* – Women's FGD participant, Village 17, agro-pastoral

[4]Berenil® - Diminazene Aceturate and Phenazone granules for an injectable solution against trypanosomiasis in cattle. Commonly referred to as "Berelin" in Maasai/Swahili usage.

Q7. *I: So when the livestock does not get better you go and get another medicine and inject? Rs: Yes.*
I: So you try different medicine until [you get] the one that responds? Rs: Yes. R8: When the livestock gets better you don't know which medicine worked.
I: That's a problem, how do you know the medicine that cured it, it might be the medicine that you used earlier [that] cured it? So, you just go on guessing? Rs: Yes.
I: So you don't have any adviser?
R1: There is no expert that is close. –Women's FGD participants, Village 13, agro-pastoral

As the quotes demonstrate self-treatment decisions and options are often contingent on past experience and shared knowledge, past experimentations, and not uncommonly, a lack of other options.

Self-Treatment Based on Advice

While perceptions of self as expert were common among respondents, self-treatment does not preclude seeking advice either from formal health providers or from their own social networks.

Q8. *R1: When I go to this elder I explain the signs on my cattle and he can tell me I treated my livestock on same disease this way and using certain cc (cubic centimetre) so I go to do the same.*
I: So you take knowledge from a person who has experienced the same problem? R3: We use that way. –Women's FGD participants, village 17, agro-pastoral

In some cases, participants reported travelling to an agrovet to buy medication and while there, they may ask for advice on the course of treatment:

Q9. *I: What if it's a new disease you have never seen, are you still going to treat yourself?*
R1: That is where the problem is.
R4: You just treat saying maybe its tryps or CBPP/CCPP [Contagious Bovine Pleuropneumonia/Contagious Caprine Pleuropneumonia]
R7: It means you get to the shop and explain yourself. The LFO will tell you to take this medicine then inject maybe a certain cc according to the instruction, so when you get home you inject according to the instruction given. – Women's FGD participants, Village 13, agro-pastoral

People recognise that formal experts sometimes also are guessing, as they are not basing advice on direct diagnostics or even clinical evaluation but reported conditions from livestock keepers. Participants also reported being able to treat livestock themselves due to having received advice prior from a formal health provider (such as an LFO or agrovet):

Q10. *R: By the time you go to buy medicine you will have already talked to the doctor [LFO] at a certain point and treated your livestock so you will have learned something from that. So, when the livestock gets sick suddenly and you don't have the doctor's communication you take action by following the instructions that you got earlier.* –Women's FGD participants, Village 20, agro-pastoral

So, while participants reported being able to administer medication themselves, in many cases they still rely on expert advice to do so.

Preference for Local Practise

Building off past experience, prior advice, trial and error, and cultural norms and practises, livestock keepers build up a skillset that demonstrates clear preferences for some types of treatments over others. Quite often, people directly expressed their preference for lay treatments, for using herbal remedies, or self-diagnosis and treatment. Use of herbs, roots, barks, other local remedies, and traditional management practises (herein all referred to as "local remedies") are commonplace across field sites, however there was a greater propensity for local remedies in pastoralist communities, where there is often pride in knowing how to treat both human and livestock ailments rooted in traditional or local environmental knowledge.

Q11. *I: Are there other traditional medicines that are used to treat livestock when they get sick?*
R1: For me I remember only those I have mentioned for treating Olodokulak [babesiosis].
R2: For livestock who have retained the placenta they were given a drug called Olemudong'o [. . .] yes you go to the forest/bush, take those medicines then you boil it and leave it to cool then you give to an animal with that problem. I2: Are you all using the same traditional medicines? Rs: Yes
R3: [For] a cow with Nunuk [swollen feet or lethargy] we usually apply ashes on it is back. – Womens' FGD participants, Village 6, pastoral

Contingencies and Conditionalities of Self-Treatment

While the findings suggest that there may be an apparent preference to self-treat this preference is conditional on a suite of factors mediated by existing sociocultural knowledge *and* extrinsic structural constraints. The propensity for livestock keepers to treat livestock themselves is influenced by factors such as access (e.g., prohibitive costs of formal treatment, lack of service availability) and trust in the health care system (e.g., historic relationships to the state, trust in competence) and through preference for local knowledge/remedies.

Lack of Acces

Self-treatment *and* notions of expertise are driven in part because people do not have ready access to formal treatment options, such as LFOs or trained veterinarians serving their herds. This lack of access is either because of the costs and financial constraints or lack of expertise located in a convenient (or even remotely geographically accessible) location.

Q12. *R: I prefer to treat myself, since the government does not come to provide service, I do not have a person to rely on.* – FO participant 57, pastoral

This contradiction is particularly apparent in pastoralist communities, where local knowledge and sense of self-expertise is strong and where political and economic marginalisation is also extensive.

Costs

Costs are also a prohibitive factor when deciding whether to use formal health providers. Often, LFOs are only able to visit a sick livestock if they deem the service to be financially viable in order to offset expenses incurred via fuel, medicines etc:

> **Q13**. *I: Do you have a livestock officer here (in the village)?*
> *Rs: There is no livestock officer.*
> *I: How about in the ward?*
> *Rs: S/he [sic] is present. R4: To call for him is costly.*
> *I: So the main reason people don't use the livestock officer is the cost? Rs:Yes. R4: And you can call him/her but until s/he comes the livestock will have died because he does not come the same day, he stays two to three days without coming so you can't wait for him. R3: If you call him and inform him about two or one livestock he might not come. R4: He wants the number of livestock to be big.*
> *I: So he wants the number to be big for him to come?*
> *R3: Yes.*
> *I: But if it is two cattle?*
> *R3: If it is two cattle he won't come. I:Even if you pay him?*
> *R1: Maybe if paid he will come, under your cost.* –Women's FGD participants, Village 17, agro-pastoral
> **Q14**. *R: Because now it is like a business, so when you phone a livestock doctor s/he will respond immediately.*
> *I: Really?*
> *R: Because s/he will earn money, they are doing business and they are not helping for free.* –Men's FGD participants, Village 23, pastoral

Thus, the combination of costs, the uneven ratios of service provision and livestock across the region, and varying levels of infrastructure for transportation or communication highlight that there are multiple ways that health inequities can occur.

Trust in Treatments, Providers, and the Health System

In some cases, a sense of self as expert casts doubt on the treatment capabilities of formal providers, compared to the experience of village elders. This belief reinforces the sentiment that they themselves are livestock experts and therefore are best placed to decide on appropriate treatments for their livestock, but also highlights the dangers of being too reliant on others who might prove to be unreliable:

> **Q15**. *R: Even I can treat myself if the doctor tells me that the medicine is this I can treat alone. You know there is a medicine which is not allowed to be administered intramuscularly or others [that] are administered subcutaneously.*
> *The vet should just instruct me how to treat.*
> *I: Why?*
> *R: You know there is a Swahili proverb:*
> *"Mtegemea cha nduguye hufa masikini" which means that "He who relies on his brother's property dies poor," so it is good if you know yourself.* – FO participant 25, pastoral

What at first glance then seems to be a preference for local knowledge and a confidence in self-expertise, soon reveals a much more complex narrative:

> **Q16**.*I: You treat it yourself? R2: We don't have a livestock officer here we treat ourselves. R5: We treat our self. I: So you are all doctors? R2: We are doctors. I: Or the seller gives you instruction? R3: If you ask, he will give you instruction. I: There is no time when you call the livestock officer? R4: None. R2: You call the livestock officer if the problem has become big, meaning in your boma* [compound where extended household and livestock reside*] many livestock are sick but if it is one or two you treat. R6: The problem is that the doctor can be called but he cannot treat better than this elder. I: This elder can have more experience than the livestock officer? R6: He knows more than the livestock officer that is in this area [...] maybe the district people know that a certain disease has erupted and [they] use the ward or district livestock officer, or there is vaccination to be done that is when he does the work. But in the boma [homestead] of this elder he goes to the medicine shop to explain his cattle's sickness and he is given medicine. R5: Or he goes and asks for a certain disease using his experience, so we are not at that point of waiting until the livestock officer tells you it is a certain disease.* –Men's FGD participants, Village 9, pastoral

The "preference" for self-treatment is also rooted in long standing relationships with the state established at independence. Different state regimes were associated with either showing livestock keepers *how* to treat livestock (e.g., introduction of clinical veterinary services during the Nyerere era) or for the dependence on self-reliance due to withdrawal of state services in rural areas (a result of changing governance to public services) as presented in the quote below:

> **Q17**. *R1: Yes, we just inject the teremice*[5] *[sic] (with luck) and God will heal an animal.*
> *I: From where or whom have you learned how to administer the drug to an animal by injection? Or you have observed the LFO or livestock doctor doing that? Rs: Laugh. R1: Who taught us before? R2: Nyerere! It is Nyerere who was the first to use this way of treating animals with these artificial drugs. [Other respondents laugh]. R3: What? Nyerere was the one taught us how to administer the drug via injection? R2: No but he [his government] was the first to bring livestock medicines.*
> *I: Okay and how about injection, the specific area to be injected by that medicine or drug you were shown by Nyerere?*
> *R2: I know it myself. R1: Sometimes we learn from other people who know how and where to inject animal then later you will go to inject your animals.*
> *I: So you learn from other people?*
> *Rs: Yes. R2: You know I am not lying when I said Nyerere because the cattle have the first injection in Nyerere regime.*
> *I: Yes. R2: After Nyerere injected the cattle in the [cattle] crush every one of us observed and from there we learned to how conduct an injection to our animals. -*
> -Women's FGD participants, Village 6, pastoral

While President Nyerere is associated with introducing biomedicine equitably through socialised care,[6] subsequent state regimes have left livestock keepers feeling resigned to the

[5]Terramycin® is a brand name for an injectable oxytetracycline however it has been shortened to "teremice" in the Swahili/Maasai usage.

[6]Participants often compared the socialist pre-SAP state under president Nyerere to current state regimes, the former associated with nostalgic times of post-independence nation building and unity, and the latter which are associated with worsened economic conditions and diminished public and veterinary health infrastructure.

lack of services, and thus the impetus to keep treating livestock themselves due to lack of alternatives.

> **Q18**. *I: Are you happy with the livestock services that are available in your area?*
> *R: Is just that we are already used to it but we are not happy because other livestock die a lot without knowing what is killing them but because we don't have an alternative we are happy [to do] what can we do.* – FO participant 3, agropastoral

The complicated history of certain social groups to the state has, at times, also manifested in mistrust in formal experts and in biomedical products (particularly vaccination) as seen in the quotes below:

> **Q19**.*R1: He doesn't want [to teach us to do our own vaccinations], and if he does teach us, he can give you fake medicine. R2: He does not bring fake medicine. R1: Honestly, he brings fake (or expired) medicine, there are cattle of ours which he vaccinated and many of them died, those which didn't die, the area [on their body] that was injected had insects [sic] coming out.* –Men's FGD participants, Village 18, agro-pastoral
> **Q20**. *R: We also think those people who manufacture medicine are business oriented. When you give the cattle certain medicine [there] has to come a time [when the] medicine [becomes] outdated and you have to go and buy again. We suspect even when you give livestock deworming medicine that is when the worms reproduce more. At that time when you give them the medicine the worms will die but when the worms become full again you have to go back to buy the medicine.* –Women's FGD participant, Village 20, agro-pastoral

In some cases, previous negative experiences with biomedicine, such as problematic vaccination campaigns in which animals died and during which incomplete information was provided about risks, can lead to participants believing formal providers lack the appropriate skills and technical capacity to administer medication.

> **Q21**. *R: The government should bring good experts for testing cattle because, for example, the person who vaccinated cattle [which] then got humps doesn't see that it has caused the citizens not to have faith in the government. Like today, many people did not bring cattle [to the sampling site] because of the vaccination done [in the past] and it is just a person who made a mistake. The government should plan well when bringing those people for vaccination and they should give us experts that vaccinate cattle at a level that is required.* –Women's FGD participant, Village 20, agro-pastoral

Thus, self-reliance has limitations, is conditional, and when self-treatment options are exhausted, people move on to formal treatments, if they can.

> ***Q22**.I: So people don't use her [LFO] because she's far or they already know how to treat so they don't see the reason of using her? R1: No, it's not because she's far, if you have a problem at your house you go to her, and she has a vet shop, so when you find her at the shop you explain [your problem] to her, buy the medicine and she gives instructions. I: So she is the one at the vet shop?*
> *Rs: Yes, she's the one that sells.*
> *I: So when you go to the shop she is one who gives all the instruction?*
> *Rs: Yes.*
> *R5: When you fail completely she does the follow up.*
> *I: That is when she comes here? Rs: Yes.*
> *I: So people use the LFO when they have failed to treat [themselves]? Rs: Yes. R4: When she gives you medicine and it does not work she changes it, when you fail she comes to your home to check the livestock and treat them. R7: When you call this LFO to come and check the cattle for diseases, it is expensive, you have to pay, and that's why many people are afraid to use her. R1: We can't use her, it's very expensive, if you don't have money what are you going to do?* –Women's FGD participants, Village 13, agro-pastoral

Formal Treatment as Diversified HSB Experiences: The Narratives

As self-treatment often involves a succession of treatments with livestock keepers gauging the effectiveness of the option at each step, formal treatment is most commonly engaged at the "end" or as a last resort within a livestock keeper's HSB process. When options are exhausted, and no positive changes in an animal's conditions are observed, an LFO (where available) is called to come and examine or diagnose the sick animal. In addition to the last resort problem, seeking formal expertise also occurs when conditions arise that participants do not feel they have sufficient capabilities to manage on their own e.g., for unfamiliar diseases, wider disease outbreaks, or known acute illnesses such as anthrax. This however is not always the situation across all study sites. Smallholder (including agro-pastoral and peri-urban communities) or where livestock keepers more commonly have exotic breeds and fewer livestock, LFOs are called more regularly as first line treatment and the sense of "self as expert" is not as pronounced as in other areas, and many perceive the stakes as being too great to *not* call a vet. However, in our study communities where the rates of endemic zoonoses are highest, i.e., pastoralist then agro-pastoralist communities (2, 5) formal treatment via LFOs is still the last step in the HSB process and the sense of "self as expert" was expressed more often amongst pastoralist respondents [see also Mangesho et al. (43)]. Thus, like self-treatment, formal treatment is often conditional and influenced by cost, severity of the health condition, personal sense of ability to treat, and availability of services; and formal treatment is most commonly used as a last resort measure.

When All Other Options Are Exhausted and the Agrovet Options Don't Work, i.e., the Last Resort

While agrovets are often the first line of formal treatment (i.e., for purchasing drugs) they are also used as sources of advice about drugs or conditions livestock may have. This process tends to be provisional on (a) prior advice from another expert or past experience; (b) availability and convenience; and (c) costs. Agrovets are also commonly only sought after some initial consultation (with elders, with others in one's household) or after failing to achieve improvement or resolution using medicines already at home. These scenarios are evidenced in the quotes below:

Q23.*I: How many times do you treat until you change the medicine? R: When you put the medicine and see that the livestock is not changing you can go and look for instruction from the livestock doctor and say there is a livestock of mine that is in this [or that] condition, I have given this medicine and it's (condition) is not changing, what other medicine should I try? You will hear him … try this, that is the explanation of the livestock officer.* –FO participant 15, agro-pastoral

Q24.*I: So what you do is that when you see a livestock is sick you go to the shop, explain to the seller and he gives you directions for treatment? R3: Even by using this phone I can call the livestock officer, explain the condition of the livestock which then he explains to me what to do, I take the medicine and use the measurements explained to me. I: Is it costly to call* [phone] *the livestock officer? Rs: Yes.* –Mixed FGD participants, Village 22, agro-pastoral

Q25.*R3: You see the livestock officer. I: So livestock officer has to come and see the livestock? R6: You explain to him the situation. I: You phone him? R6: You can phone him and explain the situation and he will advise you on which medicine to use or you can go to the livestock medicine shop and explain the condition of your livestock then they can provide service.* –Men's FGD participants, Village 10, agro-pastoral

The LFO coming to one's house for evaluation and treatment is the ultimate last resort, and only occurs if trust between the community and veterinary services or government exists.

Q26. *R: You have to go through that process since you are looking for any way for treatment, so if you get angry [that there are no services] you will ruin or lose your livestock.*
I: Ok, if it happens that some other time your livestock get a [serious] problem … will you call the vet or?
R: When you look at it, I can't do it with my own knowledge, at times a different condition might happen and I see that this medicine that I am using can't treat that disease and I have to go and see the doctor/vet or livestock officer, to do the follow up. [This happened and…] I explained to him the diseases that they had so he came with his medicine and gave it to the livestock, and after that it [the illness] did not continue and the other livestock recovered. –FO participant 15, agro-pastoral

When this trust has broken down, LFOs may not be used, even as a last resort.

Q27. *R: When the doctor is administering the medicine he must be sure the medicine will help, also that the customer and the livestock keeper are satisfied. Sometimes someone might say the doctor treated [your animal] so why are the livestock still not in good condition? So if he is not sure of what he's doing that's when there will be a competition (between doctor and livestock keeper), and maybe the doctor does not see the importance of the livestock like I do.* –Men's FGD participants, Village 20, agro-pastoral

Regular LFO Use

In the few cases where participants stated they rely primarily on LFOs, even for general malaise, it is in villages where they are readily available or are supplemented by community livestock health workers and other non-state paraprofessionals. Thus, the lines of "formal" treatment are again blurry as recognition of paraprofessionals varies district-to-district.

Vaccinations and specific disease outbreaks also serve as mediating forces in HSB for professional, formal care, including care from district officers or sometimes researchers. In these instances, people always rely on the LFOs, though this is in part because diagnosis or vaccines are not available/for sale to livestock keepers directly, as seen in Q14.

Finally, the use of self-treatment options and their surrounding contingencies does not necessarily preclude a desire for more access to expertise and professional assessment, either in the form of an actual service provider or more information or education that can facilitate further, more effective self-treatment. However, this too is predicated on past experiences and trust with the system.

Q28. *I: So for example when a livestock is sick would you like to call a doctor to treat or you will treat yourself.*
R: If the doctor is near I would like to call him to come and inspect and test the livestock.
I: Why do you like to call the doctor and not treat yourself?
R: He's an expert. –FO participant 20, agro-pastoral

Throughout the interviews and FGDs people expressed a desire for more services, better care, and more interaction (including seminars and education) from district/government veterinarians and extension officers.

DISCUSSION

Craddock and Hinchliffe (54) point to the need for in-depth qualitative methods to be an integral part of One Health research because of the unique ability of social sciences to foreground uneven geographies; frame health problems in terms of suffering and loss and not just risk; analyse relationships and situations that produce precarious bodies in the first place; and foreground the voices of those experiencing health and illness. The adoption of more in-depth, nuanced approaches that situates individual health behaviours within the contexts in which people live, as advocated in this study, has allowed us to describe the complex, non-linear and contingent narratives of HSBs. This process has allowed us to reveal the multiple, interconnected bio-social factors (such as agency, access, and trust) which influence health-related decision-making which discrete categories within KAP studies may fail to show, as they tend to focus on awareness of specific diseases, risks, or conditions.

The ways people "think and act" cannot and should not be distilled down to individual "pieces of information" [(55), p. 154]. Situating individual decision-making, actions, or "knowledge" within the contexts in which health and illness occur can reveal people's abilities or sense of agency to be able to care for their livestock, and which are part of broader bio-social systems. These issues are not always acknowledged by biomedical audiences. Thus, the idea commonly promoted through health interventions (and KAP studies as well) is often that one's sense of agency will change merely with good advice or the right information, i.e., through increased "knowledge" and thus health interventions can be directed towards these gaps in knowledge (56, 57), disease risks can be mitigated [as for zoonoses, see Zhang et al. (58)

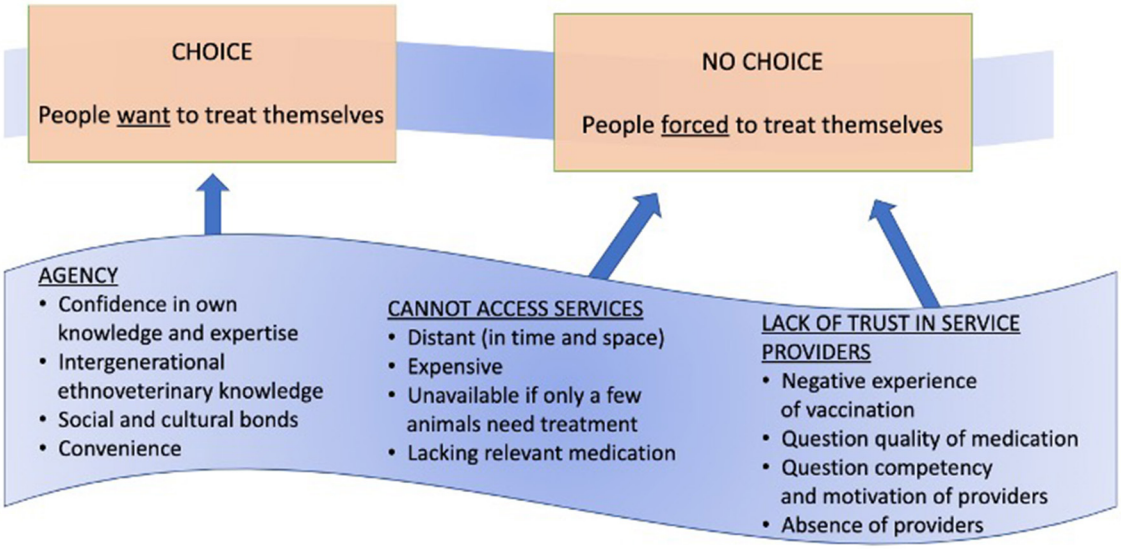

FIGURE 3 | Agency, access and trust as interdependent aspects of health seeking behaviours.

for review], or at a minimum stimulate discussion for improving health outcomes (59). However, we recognise agency and ability to shift behaviour is mediated not just through knowledge acquisition or shifting attitudes, but through social interactions and broader political-economic landscapes. We therefore suggest that in-depth social science can help reveal heterogeneity of local practise, values, and socially constructed realities that mediate health choices while also shaping human-non human relationships, especially where the porous boundaries between humans and non-humans can affect disease risks and health experiences. Because we "share our social, political, and medical landscapes with numerous biological beings," governance of zoonoses, for example, cannot be concerned with human health alone [(60). p. 6]. These aspects of health are too easily neglected in health policies and within health systems. It is not only One Health approaches that point to the importance of recognising these linkages, but so do more holistic approaches to health and well-being (8, 61).

From our findings, we suggest that health seeking behaviours are constructed from a limited set of options that people face with limited capabilities and within which *access* and *trust* arise as paramount factors in the process. Such factors are not necessarily captured within KAP-style studies yet are critical to influencing how people can act when responding to livestock illness. *Access* to and *trust* in health care options/systems in turn affect patients and livestock keepers' individual and collective agency to affect change and positive health outcomes for themselves and their livestock.

Access

Our data demonstrates communities define and access expertise and care in complex and contingent ways. Therefore, the ability for people to make "good" or rational decisions within the constraints they face (their agency) is not always straightforward or singular (see **Figure 3**). For example, while some respondents choose to self-treat due to perceptions of "self as expert" (and therefore feel they have no need to access formal services), in some cases this is a "false preference" and is directly linked to poor provision of health services within one's community. While many livestock keepers have deep generational knowledge, observational skills, and the cultural knowledge and experiences as livestock experts (43, 62), this does not lessen the significant sentiment (that many participants expressed) that the reason they self-treat is due to lack of available professionals in the area or prohibitive costs when they are available. While some LFOs are reachable via phone to offer advice, they are rarely able to visit the sick livestock or administer treatment due to limited infrastructure, transport, value for money and high work demands. In general, they are described by participants as being distant (in time and space) or completely absent, expensive, unavailable, or inaccessible. When they are available, they are often seen to be lacking in appropriate diagnostic supplies or drugs. However, this is not universal and communities of smaller geographic size, closer proximity to cities/towns, and of specific livelihoods (i.e., smallholders) tend to have better access to services. This is true for both human and livestock health services. Thus, access is impacted by broader health structure inequalities that are found at micro and macro scales within and outside Tanzania. Moreover, people's definitions and experiences often contrast with official policies and structures, such as the public-private provisions in Tanzania's 2006 Livestock Policy (34). In most communities, accessing care is a complex process and contingent on multiple factors.

Trust

Our data also reveals how HSB and service access are linked to issues of trust in the care experience overall. As such, increased availability of LFOs or government services would

not necessarily result in increased utilisation. Participants' trust in and perceptions about available health services plays a key role in influencing the decision to use them. Trust is tied to a community's past experience with government services, and sometimes is linked to long histories with the state that span past colonial and postcolonial administrations. Trust is also linked to an individual or community's belief in the service provider's competence (e.g., treatment capabilities, knowledge and skills), their motivations (e.g., being business oriented rather than genuine desire to help), or in the quality of drugs administered. Additionally, the responsiveness (or lack of responsiveness) when formal service providers are called add to people's levels of trust in the system. Historical relationships to the state, to formal services (health and beyond) also shape people's acceptance, use, and reliance on it (8). When LFOs or providers are expedient, available and helpful (in providing care, information, or education), this builds trust, reliance and use. When these are absent, this leaves participants little choice other than to rely on themselves to administer treatment to their livestock themselves, or to not treat livestock at all. Thus, the self-reliance and self perception of expertise and "choice" that people have built into their HSB are not only about access to but also trust in the services that are available.

Agency

Recognising the importance of access and trust within health seeking behaviour highlights the limits of people's agency in their health seeking behaviours. We stress that it is critical to recognise that people's sense of agency is multi-dimensional. For example, on the one hand, agency can be a component of empowerment, where people experience a sense of self sufficiency, confidence, and belief in their own knowledge, experience and expertise and as such are able to make decisions that improve livestock health outcomes. Yet this can butt against the limitations of access to services, like diagnostics or vaccines that require formal, professional expertise. On the other hand, negative experiences with the livestock health system and a sense of lack of choice or poor choices can hamper decision options or health outcomes. Thus, while we saw various aspects of agency play out across all field sites, as stated above, an overreliance on personal choice, empowerment and livestock keeper agency in livestock health outcomes should not draw attention away from the key structural inequalities of health that persist in human and veterinary health systems in Tanzania or globally.

Structural Inequities

Recognising that the existence of possible courses of actions is dependent upon wider issues of prior experience and trust in formal systems of provision highlights the need to take into account those factors that lead to individuals developing a sense of active agency. Our findings and analysis suggest that linking health choices to broader factors that shape these choices (and hence binding issues of agency to trust and access) can help further frame HSB and health interventions in East Africa and beyond. Likewise, structural inequalities of health are not just bound to national and global inequities but can also be tied to structural issues within particular health systems themselves, or within communities, households and families which have their own hierarchies of power, cultural norms, and practises that affect day-to-day health care decisions and options (63, 64). Rylko-Bauer and Farmer (65) take care to link not only structural inequalities to structural violence (a now long emphasised view of the seriousness, pervasiveness, and embeddedness of health in broader structural factors), but also to suffering, which further humanises the concept. These authors also link Sen's notions of agency (66) to structural violence of health stating it is vital to see the ways agency is constrained by the "matrix of culture, history, and political economy" [(65), p. 52] and how this is in turn linked to suffering. To address structural violence of health, suffering, likewise needs to be seen, and yet, it often remains silent or "invisible" [(65), p. 52, (67)] though it is in plain view, it is just not "dramatic." This may be doubly so for the unseen suffering of animals (outside the well-recognised effects of livestock health on people and their livelihoods). The lack of health services, the acceptance of "self-expertise" in lieu of other options, are normalised and undramatic, and may seem "empowering" when they may be the opposite. How can health services be better addressed, more evenly distributed to communities who need it, and yet who may be resistant to increased attention due to histories of poor trust? We argue for seeing and addressing both the structural inequity of health at global, national, and local scales as well as for more provider engagement with the communities they serve in order to improve health services provision and access and which will contribute to improved trust and empowerment, particularly for veterinary based HSBs.

Empowerment

Empowerment, as a development of sense of agency to enact change, is bound to complex and intertwined factors such as *access and trust* as they are in other facets of life (8, 68). Individual and community empowerment is bound to accessing one's rights as well as one's history, past experiences (either positive or negative), knowledge, and belief that one can make effective change or have a positive impact (69). However, empowerment alone is insufficient to improve health outcomes or meet health needs (for either people or their livestock). While the ability to make "good" health decisions may be a critical component of health justice (69) it still places the central control of health outcomes into *individual* decision making. Our approach demonstrates the need to look beyond individual behaviours and to scrutinise more thoroughly the contextual and structural factors that influence the extent to which an individual is able to act. As we have highlighted in this discussion, issues relating to access and trust become critical threads throughout these decisions (70).

CONCLUSION

Our research demonstrates how structural inequalities of health may be reproduced through health seeking behaviours, misplaced notions of individuality, agency, and empowerment in HSB and the reproduction of structural factors that inhibit an individual's ability to act. We paid particular attention to health choices and options for livestock keepers and their livestock and

demonstrated the need to be mindful of broader and immediate contextual factors that impact health and well-being. We point to how access and trust are key factors in HSB, and how these tie into issues of structural inequalities of health. Finally, we argue for more engaged, in-depth social science research of (veterinary) health to move beyond individual KAP based studies, draw out the complex factors that shape behaviour, and bring attentiveness to the role of the wider social contexts within which human and animal health occur.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Kilimanjaro Christian Medical Centre (KCMC/832) and National Institute of Medical Research (NIMR/2028) in Tanzania, College of Medical, Veterinary and Life Sciences at the University of Glasgow (39a/15). Approval for study activities for each researcher was also provided by the Tanzanian Commission for Science and Technology (COSTECH) and by the Tanzanian Ministry of Livestock and Fisheries, as well as by regional, district, ward and village-level authorities in the study area. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

AD, JV, JS, SC, BM, JC, ES, WG, and JH contributed to the conceptualisation and design of the study. JS, SC, JB, and JC contributed to funding acquisition. AD, FL, KT, ES, WG, KM, TM, and MT were responsible for data curation, investigation, analysis, and project administration. AD, JV, and JS performed analysis and wrote the first draught of the manuscript. ES, WG, TM, SC, JH, KT, JC, and FL contributed writing and revision of the manuscript. All authors have approved the submitted version.

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Understanding the Relationships Between the Consumer Perception on Food Risks, Quality, and Safety Indicators of Braised Meat Sold in "Dibiterie" Restaurants in Dakar, Senegal

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Dibiteries are restaurants that sell braised meat of small ruminants and sometimes chicken. Current microbiological data indicate that the products sold are sometimes contaminated with pathogenic microorganisms exceeding the quality standards recommended for human consumption, hence a real public health concern. Despite the lack of hygiene, these establishments continue to thrive in the Senegalese food ecosystem. However, very few studies have analyzed the socio-economic motivations and risk representations of these populations who participate in the growing demand for meat from dibiteries. The main objective is to understand the relationships between consumer perception of food risks, quality, and safety indicators of braised meat sold in Dibiteries in Dakar. A total of 479 people from 404 households in the Dakar region were randomly selected and surveyed on the consumption of dibiterie meat using a structured questionnaire. The questionnaire allowed to measure the relative importance given by each interviewee to the indicators related to the risk of food infection, and the quality and safety of dibiterie meat. The structural equation model was used to design the paths and analyze the relationships. Of the 479 people interviewed, 291 people consumed dibiterie meat. Only 16% of consumers strongly perceive the quality and safety of meat. This strong perception has been positively associated with monthly food expenditure, while the age of consumers explained it negatively. Among the latent variables identified, the perceived price effect and the dibiteries' expertise were positively related to the perception on the safety and the perception on the nutritional quality of the product. The nutritional quality of the product had negatively impacted the risks of food infection perceived by consumers. The results of this study suggest the strengthening of hygiene standards in dibiteries and the awareness of consumers, especially young people, about the potential health risks associated with the consumption of dibiterie meat. Further work on willingness to pay to improve the safety of dibiterie meat is needed.

Keywords: dibiterie, meat, perception, quality, safety, risk, structural equation model, Senegal

INTRODUCTION

Animal source foods are essential for the nutrition and livelihoods of low-income populations in sub-Saharan Africa. In low- and middle-income countries (LMICs), they contribute significantly to diets. The demand for fish, milk, and meat will continue to grow over the coming decades, thanks to population growth and changing consumption practices linked to urbanization and rising incomes.

Meat is an important element of the daily diet for much of society and is considered as a valuable food from a nutritional point of view (1). Indeed, meat provides important nutritional elements including proteins, fats, vitamins, and minerals that effectively contribute to the normal functioning of consumers' bodily systems (2). Although the benefits of meat consumption are significant, meat is a highly perishable product and can often cause food poisoning in consumers due to poor conditions of transport, storage, processing, or marketing. Therefore, the monitoring of food safety risks across all animal production chains (from stable to table) is of great interest. In addition, a diet rich in meat can also have a potential negative effect on human health due to the high content of cholesterol and saturated fatty acids that may be contained in meat (3). For red meats, such as beef, mutton, and pork, studies have associated a reduction of their consumption as a reflex response linked to the individual perceptions of health risks (4, 5). The levels of cholesterol and saturated fat in red meats have been reported as specific health factors influencing consumer choices (6, 7).

Meat consumption habits are unpredictable due to the constant changes in consumer behavior toward meat and other food products (8). For consumers to voluntarily buy and consume a particular meat product, their perception of it must be positive. If consumers have a negative perception of a meat product, their purchasing behavior will be negatively affected (9). Consumer behavior toward food, especially meat, is characterized by changing preferences (10). Indeed, food choice is a phenomenon resulting from the interaction between a variety of factors (11). Thus, consumers consider several characteristics to determine food product acceptance, sensory characteristics, nutritional value, convenience, and its impact on their health (12, 13). Indeed, in addition to the price of the product frequently targeted by consumers, factors such as appearance, convenience and perceived quality as well as safety (14, 15), social, individual, economic, and cultural aspects influence decisions taken on the market place (8). Thus, consumers now require safe and good quality food products at a reasonable price (15). Therefore, understanding consumer behavior becomes vitally important, as the way in which consumers' expectations are met decisively influences their purchasing decisions (16, 17).

In sub-Saharan Africa, the food processing and marketing link dominated by catering is growing rapidly, particularly in the informal sector where animal source products are sold at affordable prices and highly appreciated especially by populations with low income. However, the technologies and processes applied in these markets by often unskilled food handling personnel make the finished products unfit for human consumption. This is the case in Senegal with small food processing units operating in the informal sector, called "Dibiterie." These restaurants offer braised meat of small ruminants and sometimes chicken for human consumption. According to current evidences, the products from these restaurants are sometimes contaminated with pathogenic microorganisms exceeding the quality standards recommended for human consumption (18, 19), hence a real public health concern. This situation is linked to the non-application of certain measures of good hygiene practices by the staff. Despite the lack of hygiene, these establishments continue to thrive in the food ecosystem, thus attesting to the growing demand for these products by the Senegalese populations, whose motivations are multiple. However, very few studies have analyzed the socio-economic motivations of these populations who participate in the growing demand for dibiterie meat. In addition, the representations of the risks associated with the consumption of these products have not yet been clarified. The main objective of this study was to understand the relationships between consumer perception of food risks, quality, and safety indicators of braised meat sold in Dibiteries in Dakar. Specifically, this involves (i) characterizing the levels of perception on the quality and safety of dibiterie meat; (ii) identifying the factors associated with levels of perception of the quality and safety of dibiterie meat; (iii) assessing the relationships between the variables associated with the perception of the quality and safety of dibiterie meat and their impact on the perception of the risk of food infection; and (iv) determining the representations of the risks associated with the consumption of dibiterie meat.

MATERIALS AND METHODS

Study Area and Target Population

This is a descriptive cross-sectional study that was carried out from November 2018 to February 2019 among consumers of dibiterie meat in households and dibiterie tenants in the Dakar region in Senegal. This region consists of the departments of Dakar, Guédiawaye, Pikine, and Rufisque. This framework of investigation was chosen because the department of Dakar is the main pole of demand for products of animal source food due to the large share, i.e., 23% (3,529,300 inhabitants) of the population of Senegal, it concentrates (20). In addition, consumers who reside there have a higher purchasing power compared to other regions. However, the suburb of Dakar represented by the departments of Pikine, Guédiawaye, and Rufisque brings together ∼63% of the region's population. In addition, the department of Pikine is home to the Dakar region slaughterhouse. The management of this slaughterhouse is ensured by the Société de Gestion des Abattoirs du Sénégal (SOGAS). The department of Pikine is therefore a crossroads for households and tenants of dibiteries in search of good meat quality for human consumption.

Sampling and Sample Size

Household sampling was performed using the simple random method and the sample size n was estimated using Thrusfield's formula (21):

$$n = \frac{[Z^2 * p(1-p)]}{d^2} \quad (1)$$

with n = the number of households to be surveyed; $Z = 1.96$ (confidence level deduced from the 95% confidence rate); $p =$ 50% (expected prevalence of households consuming dibiterie meat); $d = 5\%$ (margin of error).

The sample size is 384 households. In order to have the maximum number of dibiterie meat consumers, the choice of neighborhoods was made in a reasoned manner and based on the distribution of dibiterie establishments in the Dakar region. Indeed, Orou Seko (22) found that the dibiteries are mainly located in popular neighborhoods in the Dakar region. Thus, the first step was to investigate the popular neighborhoods covered by this study. High-income neighborhoods have been associated to these different popular neighborhoods. Knowing that income strongly determines the purchasing power and type of housing of households, the neighborhoods to be sampled were first divided into three groups according to a classification adopted by Mankor (23) associated with the results of the study by Orou Seko (22). These are low-income popular neighborhoods, middle-income popular neighborhoods, and high-income neighborhoods. Based on the income level and the housing type of the neighborhoods, a random draw was made to obtain representative neighborhoods of the three groups and the sample size was proportionally distributed over all the selected neighborhoods.

Within each neighborhood, the choice of households and people to be surveyed was made randomly and according to their availability and willingness to answer our questions. In order to avoid gender bias, three members within each household—a man, a woman, and a young person (man or woman)—were surveyed. Inclusion of people was based on the following criteria: (i) individuals of both sexes who had agreed to participate in the investigation by signing the informed consent form; (ii) persons aged at least 16 years who have obtained the consent of one of the parents or a member of the family. At the end of the investigations, 478 people including 291 consumers of dibiterie meat were surveyed. The distribution of this size by gender shows a non-significant difference, i.e., 215 men (45%) and 263 women (55%). The socio-economic and demographic profile of the sample of dibiterie meat consumers is presented in **Table 1**.

Moreover, at the Dakar slaughterhouse located in the department of Pikine, six meat consumers (men and women) and two dibiterie tenants were selected, respectively, for a focus group discussion (FGD) and semi-structured interviews.

Theoretical Framework and Study Design

Rapid economic development and recent changes in the food supply chain have contributed to increased interest in the issues of quality and safety in the food sector. In the minds of consumers, the notion of the quality of a food product appears to be closely linked to the perception of its safety. A study investigating the relationship between food quality and safety has found that people seem more prone to regard a food product as safe if they consider it to be of high quality rather than the opposite (24). Several studies have highlighted the fact that the definition of quality is not unified but rather depends on the different perspective from which it is evaluated: a definition in technical and production terms may differ from the perception of consumers (25). From the point of view of consumers, in fact, several aspects help to define the quality of a food product: these are not only intrinsic qualities such as taste and other organoleptic properties, but also external factors such as origin and labeling (26, 27).

The quality theory based on the information economics approach to user-oriented quality was used for the design of this study (28). Indeed, consumers look for high-quality food products and they infer this quality on the basis of a certain group of indicators, or attributes, which are classified according to the degree of visibility, namely: the search, experience, and credence or belief attributes (29). This approach has been applied to meat by many authors (30, 31). Firstly, there are the search or expected quality indicators and often referred to as "quality cues"—the evaluation of indicators of the nature of the products to be purchased. These attributes can be classified into two types, intrinsic and extrinsic cues. Intrinsic cues, described as visible inherent characteristics of the product, are important in determining quality expectations in many categories of fresh foods. Extrinsic indicators represent information related to the product but which is not physically part of the product, which can be modified externally (31). Secondly, there are experienced quality indicators that can only be revealed after purchasing and consuming the product. However, according to Verbeke et al. (32), consumers expect the experience quality to meet their expectations and, therefore, are increasingly more open to the use of extrinsic cues to support such evaluations. Thirdly, there are indicators of the credence or belief quality—characteristics that persist even after purchasing and consuming the product. Belief quality attributes are those that consumers can never assess with confidence but based on consumers' opinions of the product itself or the producer, even after consumption (29, 31). This involves health and process benefits (which may satisfy moral and ethical needs), and a consumer cannot with any degree of certainty assess or confirm their existence.

Furthermore, the evidence indicates that using certain intrinsic attributes to deduce quality can be dysfunctional (33, 34). According to Henchion et al. (31), this suggests a discord between the expected and experienced quality due to a misconception of certain intrinsic indices. Grunert (35) argues that this is due to displaced reliance on intrinsic quality cues, which may be the result of relatively few extrinsic indices available to support consumer evaluations. Consequently, it undermines consumers' confidence in the sector, increases their uncertainty about quality expectations, and can lead to dissatisfaction (31). In addition, extrinsic cues offer considerable potential to support the consumer quality assessments in light of evolution of purchasing motivations linked to changing demographics, lifestyles, and knowledge, and raising concerns about safety, health and ethical factors (26, 35).

The debate around these themes focused on several aspects of the product: from organoleptic characteristics to health and hygiene safety, healthiness and nutritional qualities at the place of production, and the ethical aspects associated therewith. Based on previous studies conducted on the perception of meat quality and safety in Morocco and Tunisia (36–38), this study identified and assessed 15 variables that can influence consumers' perceptions of quality and safety of dibiterie meat in households.

TABLE 1 | Socio-economic and demographic profile of consumers of dibiterie meat in households of the Dakar region ($n = 291$).

Characteristics	Modalities	Frequency	Percentage
Gender	Male	141	48
	Female	150	52
Age (years)	16–20	15	5
	20–40	173	59
	40–60	69	24
	≥60	26	9
	Non-respondent	08	3
Ethnic group	Wolof	80	28
	Sérère	33	12
	Peulh	60	20
	Lébou	47	16
	Djola	18	6
	Other Senegalese ethnicities	20	10
	Non-Senegalese ethnicities	33	8
Religion	Muslim	262	90
	Christian	29	10
Marital status	Young	10	3
	Single	105	36
	Married	152	52
	Widower	11	4
	Divorced	13	5
	Non-respondent	00	0
Level of education	Without formal education	18	6
	Primary	78	27
	Secondary	91	31
	University	91	31
	Koranic	11	4
	Non-respondent	02	1
Socio-professional category	Public servant	22	8
	Employee	36	12
	Manual-workers	45	15
	Trader	38	13
	School-boy/Student	57	20
	Housewife	58	20
	Retired/Unemployed	13	4
	Other professions	16	6
	Non-respondent	06	2
Monthly food expenditure (FCFA*)	<25,000	07	3
	25,000–50,000	27	9
	50,000–75,000	27	9
	75,000–100,000	37	13
	>100,000	164	56
	Non-respondent	29	10
Monthly income (FCFA*)	<50,000	19	6
	50,000–100,000	46	16
	100,000–150,000	30	10
	150,000–200,000	31	11
	>200,000	119	41
	Non-respondent	46	16

**FCFA, Franc de la communauté financière africaine (1 USD = 565.1686 FCFA, https://fr.exchangerates.org.uk/convertir/USD-XOF.html).*

The indicators linked to quality were as follows: taste, smell (after cooking), price, time constraint, proximity, salesperson's expertise, dibiterie name (brand), and dibiterie renown. As for the indicators of the dibiterie meat safety, it was retained: dibiterie hygiene, place of animal slaughter, veterinary stamp, animal slaughter according to the Muslim rite, rich in vitamins, rich in energy, and microbes. For each of these attributes, the consumer had to report his attitude by indicating his degree of attachment to each of the variables on a five-point Likert scale ranging from (1) "strongly disagree" to (5) "strongly agree" on the basis of the answers to the question related to the elements encouraging consumption (for example: I consume the meat of dibiteries for its characteristic smell after cooking?).

Consumers' perceptions on the risks of food infection were also assessed. All four items related to the five keys to safer food from the WHO (39) were used. For each of these items, the consumer had to report his attitude by indicating his degree of attachment to each of the variables on a five-point Likert scale ranging from (1) "strongly disagree" to (5) "strongly agree" on the basis of the answers to the question related to the food infection risks (for example: washing hands before consuming dibiterie meat helps to prevent food infections?).

In the present study, the first step is to assess the relationships between the variables associated with the perception of quality and those related to the perception of the safety of dibiterie meat, and secondly, to determine how these relationships impact the perception of the risks of food infection using the structural equation modeling (SEM) approach. This approach was used because it allows to (i) specify and test the whole theoretical or conceptual model to determine in what extent the hypothetical model is consistent with the data; (ii) specify and test in the theoretical model more complex paths (i.e., direct and indirect) between variables; and (iii) incorporate latent variables with multiple indicators, while regression analysis would not have allowed the inclusion of several indicators (40).

Data Collection

The collection of information from households was carried out by administering a structured questionnaire in French or Wolof (local language) at home. The data collected concerned (i) the socioeconomic and demographic characteristics of the interviewees; (ii) indicators linked to the quality and safety of dibiterie meat; and (iii) the perception on the risks of food infection linked to the consumption of dibiterie meat.

The different information was collected through direct or indirect interviews depending on the level of formal education of the participant. Indeed, we sometimes used the service of an interpreter for the translation from the French language into Wolof when the people interviewed did not understand French.

In order to analyze the perceptions and social constructions of risk, an FGD and semi-structured interviews were also carried out, respectively, with the buyer-consumers of meat and the dibiterie tenants within the Dakar slaughterhouse in Pikine department.

Statistical Data Processing and Analysis

The investigation data were entered using Sphinx Plus2 version 5 software and transferred to the Microsoft 2016 Windows Excel spreadsheet. SPSS Statistics and SPSS AMOS version 23 software were used for statistical analyses of the data. Means followed by standard deviations were estimated for quantitative variables, while percentages were measured for qualitative data.

Meat quality index (MQI) estimation allowed to characterize the levels of consumer perception on the quality and safety of dibiterie meat. The MQI is an "additive index" allowing to measure the relative importance given by each interviewee to the quality of meat through their attachment to each attribute. From this index, different levels of perception of the quality and safety of dibiterie meat were identified. The groups of perceptions selected are subjective and based on the relevance of the expected results. The values of the index range from a minimum of 0 to a maximum of 1 (41). The following equation shows the formulation of the MQI.

$$MQI_i = \frac{\sum_{s=1}^{m} a_{is} * X_s}{aX} \quad (2)$$

where a_{is} an integer score given to an attribute (X_s) by interviewee i ($i = 1, 2, \ldots, n$) according to the Likert scale chosen; s is the number of attributes ($s = 1, 2, \ldots, m$); and aX is the maximum potential score that can be obtained by an interviewee (number of attributes multiplied by the maximum score defined by the Likert scale).

Thus, consumers with an MQI >70% are qualified as "strong perception," while those whose MQI are lower and higher than 50% are qualified as "weak perception" and "average perception." Multinomial logistic regression (MLR) was then performed to identify socioeconomic and demographic variables that explain the levels of perception on the quality and safety of dibiterie meat. Then, the principal component analysis (PCA) with orthogonal rotation (Varimax) allowed to identify the latent variables characterizing consumers' perceptions on the quality and safety of dibiterie meat using SPSS Statistics software version 23. A latent variable (dimension) was selected and identified if its initial eigenvalue was ≥1. A variable (item) was retained in a component if its absolute initial eigenvalue was >0.3. Using the SPSS AMOS version 23 software, these latent variables were used in a structural equation model (SEM) to identify the different relationships between the variables associated with the perception on the quality and safety and their impacts on the perception of the risks of food infection. A chi-square p-value >0.05 was considered indicative of an exact fit of the model. We have also reported goodness-of-fit indices as measures of approximate fit (42). The following fit indices were used: the root mean square error of approximation (RMSEA), Goodness of Fit Index (GFI), Comparative Fit Index (CFI), and Root Mean Square Residual (RMR). Values <0.05 indicate a good fit for RMSEA. Values close to 0 for the RMR while values ≥0.90 indicate an acceptable fit for the model and data for both the GFI and the CFI (40). Furthermore, on the basis of the model fit indicators, we modified the hypothetical model by removing the paths of the observed variables (items) having standardized

TABLE 2 | Distribution of the mean scores of the indicators of perception on the quality and safety of dibiterie meat ($n = 291$).

Category of indicators	Items	Mean of scores (SD)	Cronbach' α
Dibiterie meat quality	Taste	4.43 (0.89)	0.819
	Smell (after cooking)	4.35 (0.98)	
	Salesperson's expertise	3.58 (1.15)	
	Dibiterie renown	3.13 (1.19)	
	Dibiterie name	3.11 (1.20)	
	Price	2.46 (1.14)	
	Proximity of the dibiterie	2.39 (1.03)	
	Time constraint	2.37 (1.04)	
Dibiterie meat safety	Dibiterie hygiene	3.98 (1.04)	0.679
	Rich in vitamins	3.03 (1.17)	
	Rich in energy	2.86 (1.17)	
	Veterinary stamp	2.73 (1.19)	
	Animal slaughter according to the Muslim rite	2.59 (1.13)	
	Place of animal slaughter	2.47 (1.10)	
	Microbes	2.19 (0.76)	

SD, Standard deviation.

TABLE 3 | Characterization of the levels of perception on the quality and safety of dibiterie meat ($n = 291$).

Group of consumers	Distribution of the quality and safety index of dibiterie meat		Number of consumers	%
	Limits of variables			
Level of perception	Minimum	Maximum		
Low	0.32	0.5	43	14.78
Medium	0.51	0.70	203	69.76
High	0.71	0.88	45	15.46
Mean ± SD	0.61 ± 0.09			

SD, Standard deviation.

coefficients <0.5 (40) and the estimations were recalculated up to obtaining a model that well overall fits to the data. Therefore, several iterations were carried out to arrive at the final model.

Finally, the qualitative information from the FGD and semi-structured interviews were triangulated in order to analyze consumers' constructs on the risks associated with the consumption of dibiterie meat.

RESULTS

Levels of Perception on the Quality and Safety of Dibiterie Meat

In order of importance, the decision to consume the dibiterie meat in households was mainly based on the quality and safety attributes such as taste, dibiterie hygiene, salesperson's expertise, dibiterie renown, dibiterie name, and rich in vitamins (**Table 2**).

The value of the index of quality and safety of dibiteries meat ranged from 0.32 to 0.88. The distribution of this index indicates the existence of three levels of consumer perception according to the relative importance given to the indicators of the quality and safety of dibiterie meat (**Table 3**). The majority of consumers had a "medium perception" (index between 0.51 and 0.70) of the quality and safety of dibiterie meat (70%). Consumer groups with a "low perception" (index between 0.32 and 0.50) and a "high perception" (index between 0.71 and 0.88) of the quality and safety of dibiterie meat were less represented, i.e., ∼15% each.

Factors Associated With the Levels of Perception on the Quality and Safety of Dibiterie Meat

Taking as a reference the group of consumers with an "average perception" on the quality and safety of dibiterie meat, the results of the multinomial logistic regression are presented in **Table 4**. It emerges that the "low perception" of consumers on the quality and safety of dibiterie meat was positively influenced by the individual monthly income ($p < 0.01$) and negatively by the monthly food expenditure ($p < 0.05$). This means that, compared to the reference group (average perception), people whose monthly income is between 100,000 and 150,000 FCFA have a weak perception of the quality and safety of dibiterie meat. Also, the more people have monthly food expenses of between 50,000 and 75,000 FCFA, the less they tend to perceive weakly the quality and safety of dibiterie meat (compared to the reference group).

TABLE 4 | Multinomial logistic regression of factors associated to the levels of perception on the quality and safety of dibiterie meat ($n = 229$).

Category	*N* (%)	Levels of perception†							
		Low				High			
		B	SE	*p*	OR (95% CI)	B	SE	*p*	OR (95% CI)
Location									
Dakar	146 (64)	−0.06	0.49	0.905	0.94 (0.35–2.50)	0.15	0.49	0.76	1.16 (0.44–3.19)
Suburb	83 (36)			Reference				Reference	
Age (year)									
16–25	60 (26)	−1.34	1.31	0.305	0.26 (0.02–3.39)	−2.58	1.18	0.029**	0.07 (0.01–0.77)
26–35	75 (33)	−1.09	1.22	0.374	0.34 (0.03–3.71)	−2.06	1.09	0.059	0.13 (0.01–1.08)
36–45	47 (20)	−0.49	1.27	0.696	0.61 (0.05–7.31)	−1.91	1.13	0.091	0.15 (0.02–1.35)
46–55	20 (9)	−0.88	1.36	0.518	0.41 (0.03–6.00)	−1.83	1.20	0.128	0.16 (0.01–1.69)
56–65	15 (7)	−0.53	1.33	0.692	0.59 (0.04–8.03)	−1.82	1.26	0.150	0.16 (0.01–1.93)
≥66	12 (5)			Reference				Reference	
Gender									
Homme	120 (52)	0.36	0.48	0.447	1.44 (0.56–3.68)	0.82	0.46	0.079	2.26 (0.91–5.62)
Femme	109 (48)			Reference				Reference	
Marital status									
Not married	110 (48)	0.49	0.51	0.338	1.63 (0.6–4.43)	0.19	0.49	0.69	1.22 (0.46–3.19)
Married	119 (52)			Reference				Reference	
Formal education									
Without	19 (9)	−2.13	1.09	0.052	0.12 (0.01–1.02)	−1.31	1.28	0.307	0.27 (0.02–3.31)
Primary	60 (26)	−0.86	0.75	0.249	0.42 (0.09–1.83)	0.53	0.73	0.468	1.69 (0.41–7.08)
Secondary	74 (32)	−0.66	0.65	0.314	0.52 (0.14–1.86)	0.89	0.58	0.120	2.45 (0.79–7.59)
University	76 (33)			Reference				Reference	
Occupational status									
Non-employee	47 (20)	−0.18	1.68	0.916	0.84 (0.03–22.76)	2.15	1.53	0.158	8.60 (0.43–171.16)
Employee	54 (24)	1.19	1.51	0.427	3.30 (0.17–63.19)	1.87	1.35	0.164	6.52 (0.46–91.66)
Self-employee	75(33)	1.49	1.49	0.319	4.45 (0.24–83.93)	1.77	1.34	0.185	5.89 (0.43–80.93)
Housewife	44 (19)	0.66	1.56	0.672	1.93 (0.09–41.06)	1.32	1.37	0.336	3.76 (0.25–55.62)
Retired	9 (4)			Reference				Reference	
Individual monthly income (FCFA♣)									
<50,000	19 (8)	1.23	0.96	0.201	3.43 (0.52–22.63)	0.10	0.92	0.914	1.10 (0.18–6.74)
50,000–100,000	45 (20)	1.25	0.67	0.063	3.49 (0.93–13)	0.07	0.61	0.906	1.07 (0.32–3.56)
100,000–150,000	29 (13)	2.07	0.68	0.002***	7.90 (2.07–30.1)	−0.54	0.86	0.532	0.58 (0.11–3.15)
150,000–200,000	30 (13)	0.16	0.74	0.828	1.17 (0.274–5.04)	−1.09	0.75	0.145	0.33 (0.07–1.46)
≥200,000	106 (46)			Reference				Reference	
Monthly food expense (FCFA♣)									
<25,000	7 (3)	0.07	1.39	0.962	1.07 (0.07–16.47)	−0.05	1.35	0.969	0.95 (0.07–13.42)
25,000–50,000	27 (12)	−0.38	0.75	0.616	0.69 (0.16–2.99	−0.02	0.77	0.974	0.98 (0.22–4.39)
50,000–75,000	26 (11)	−2.00	0.90	0.027**	0.13 (0.023–0.79)	−0.75	0.81	0.355	0.47 (0.1–2.32)
75,000–100,000	33 (14)	0.661	0.58	0.257	1.94 (0.62–6.07)	1.23	0.60	0.042**	3.43 (1.05–11.25)
≥100,000	136 (60)			Reference				Reference	

***$p < 0.05$, ***$p < 0.01$; %, Percentage; SE, Standard error; OR, Odds ratio. ♣FCFA, Franc de la communauté financière africaine (1 USD = 565.1686 FCFA, https://fr.exchangerates.org.uk/convertir/USD-XOF.html).*

† Multinomial regression; Reference group: medium perception.

Quality of fit; Pearson Chi square: 49.923, Significance: 0.320.

As for the "high perception" on the quality and safety of dibiterie meat, it was negatively associated with age ($p < 0.05$) and positively with consumers' monthly food expenditure ($p < 0.05$). Thus, the more people are between 16 and 20 years old, the less strongly they perceive the quality and safety of dibiterie meat (compared to the reference group). In addition, compared to the reference group, people with monthly food expenses of between 75,000 and 100,000 FCFA tend to have a high perception on the quality and safety of dibiterie meat.

Relationships Between the Variables Linked to the Perception on the Quality and Safety of Dibiterie Meat and the Perception on the Risks of Food Infection

Identification of Latent Variables

The PCA allowed to identify the latent variables linked to the perception on the quality and safety of dibiterie meat (**Table 5**). The perception on the quality of dibiterie meat is described by

TABLE 5 | Identification of latent variables of the structural equation model.

Latent variables	Observed variables (Items)	Principal component (PC)		
		PC 1	PC 2	PC 3
Indicators of perception on the safety of dibiterie meat				
Expertise of the dibiterie	Dibiterie renown (PQ1)	0.985	0.092	0.098
	Dibiterie name (PQ2)	0.982	0.102	0.104
	Salesperson's expertise (PQ3)	0.974	0.096	0.087
Price effects	Proximity of dibiterie (PQ7)	0.092	0.988	0.042
	Time constraint (PQ6)	0.093	0.972	0.056
	Price of the dibiterie meat (PQ8)	0.098	0.962	−0.005
Organoleptic quality	Taste (after cooking) (PQ4)	0.078	0.016	0.944
	Smell (after cooking) (PQ5)	0.134	0.051	0.935
	KMO index and Bartlett test			
	Kaiser-Meyer-Olkin Index for measuring sampling quality	0.663		
	Bartlett's sphericity test	Chi-square approx. = 3,775.524; df = 28; $p = 0.000$		
	Total variance explained			
	% of variance	36.671	35.978	22.458
	Cumulative %	36.671	72.649	95.107
Indicators of perception on the safety of dibiterie meat				
Product safety	Place of animal slaughter (PS1)	0.920	−0.024	–
	Animal slaughter according to the Muslim rite (PS2)	0.913	−0.025	–
	Veterinary stamp (PS3)	0.886	−0.053	–
	Dibiterie hygiene (PS4)	0.338	0.162	–
	Microbes (PS5)	0.330	0.248	–
Nutritional quality	Rich in vitamins (PS6)	0.057	0.917	–
	Rich in energy (PS7)	−0.013	0.908	–
	KMO index and Bartlett test			
	Kaiser-Meyer-Olkin Index for measuring sampling quality	0.690		
	Bartlett's sphericity test	Chi-square approx. = 830.273; df = 21; $p = 0.000$		
	Total variance explained			
	% of variance	38.433	25.105	–
	Cumulative %	38.433	63.538	–
Perception on the risks of food infection				
Perception on the risks of food infection	Storage temperature of dibiterie meat is important to avoid food infections (PR4)	0.941	–	–
	Proper cooking of dibiterie meat is important to avoid food infections (PR3)	0.940	–	–
	Raw food can contaminate dibiterie meat (PR2)	0.475	–	–
	Hand washing before dibiterie meat consumption is important to avoid food infections (PR1)	0.373	–	–
	KMO index and Bartlett test			
	Kaiser-Meyer-Olkin Index for measuring sampling quality	0.666		
	Bartlett's sphericity test	Chi-square approx. = 548.340; df = 6; $p = 0.000$		
	Total variance explained			
	% of variance	53.352	–	–
	Cumulative %	53.352	–	–

three latent variables including "expertise of dibiterie," "price effects," and "organoleptic quality" with an explained cumulative variance of 95%. The indicators of the perception on the safety of dibiterie meat are grouped around two latent variables, "product safety" and "nutritional quality," with a cumulative explained variance of about 64%. Moreover, the perception on the risk of food infection is made up of a single factor with an explained variance of about 53%.

Estimation of the Initial Model

The initial hypothetical model (**Figure 1**) deviated significantly from the data according to the strict χ^2 test [χ^2 (df = 137,

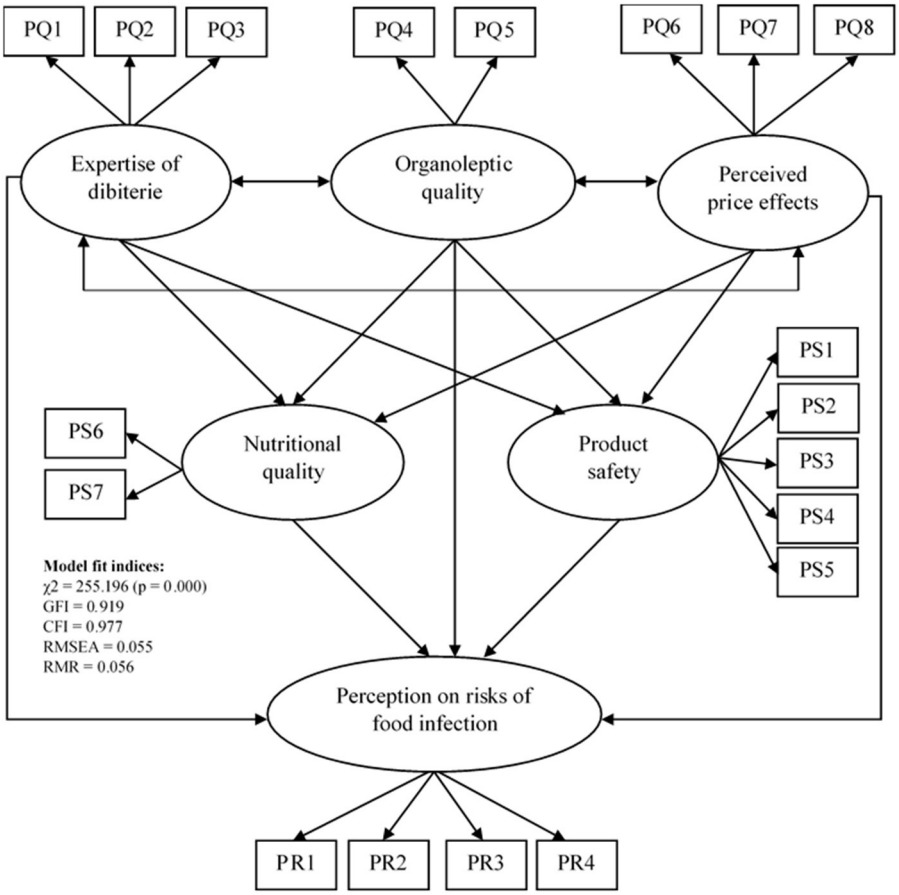

FIGURE 1 | Hypothetical relationships between the latent variables of the perception on the quality, the perception on the safety of dibiterie meat, and the perception on the risks of food infection (PQ, Perception on the quality; PS, Perception on the safety; PR, Perception on the risks).

$N = 291) = 255.196$; $p < 0.01$], although it had an acceptable fit according to the approximate fit indices (GFI = 0.919; CFI = 0.977; RMR = 0.056; RMSEA = 0.055). Furthermore, since an overall lack of fit of the model is synonymous with bias in the estimates of the individual parameters, the structure of the model was therefore modified, to obtain a satisfactory fit before proceeding to the examination of the individual estimates.

Estimation of the Final Model

The estimates following the respecification of the construct show a good fit between the final model (**Figure 2**) and the data according to the strict χ^2 test [χ^2 (df = 50, $N = 291$) = 252.215; $p > 0.05$]. The fit indices also indicate that the overall fit of the final model was acceptable (RMSEA = 0.012; GFI = 0.973; CFI = 0.998; RMR = 0.023).

Product Safety, Nutritional Quality, and Risks of Food Infection

The estimate showed that the perceived price effects was positively associated to the product safety ($\beta = 0.21$; $p < 0.001$), while the expertise of the dibiterie had a direct impact on the nutritional quality of the product ($\beta = 0.18$; $p < 0.01$). This means that the perceived price effects and the expertise of the dibiterie, respectively, increase the perception on the product safety and the perception on the nutritional quality of the product. Moreover, among the variables tested, only nutritional quality was negatively associated with the perception on the risk of food infection ($\beta = -0.15$; $p < 0.05$) (**Figure 2**). Therefore, the more the nutritional quality of the dibiterie meat is perceived, the less the risk of food infection is perceived.

Consumer Representations Toward the Risks Associated With the Consumption of Dibiterie Meat

Preferences and Incentives Related to the Consumption of Dibiterie Meat

Investigations carried out among consumers and dibiterie tenants indicate that dibiterie meat is consumed because of these nutritional, therapeutic, and organoleptic properties. However, these virtues depend on the species and the age of the animal consumed. Indeed, consumers agree that dibiterie meat prepared from goat meat and lamb meat are the most nutritious; while the meat of an adult sheep is less tender, difficult to digest and can be

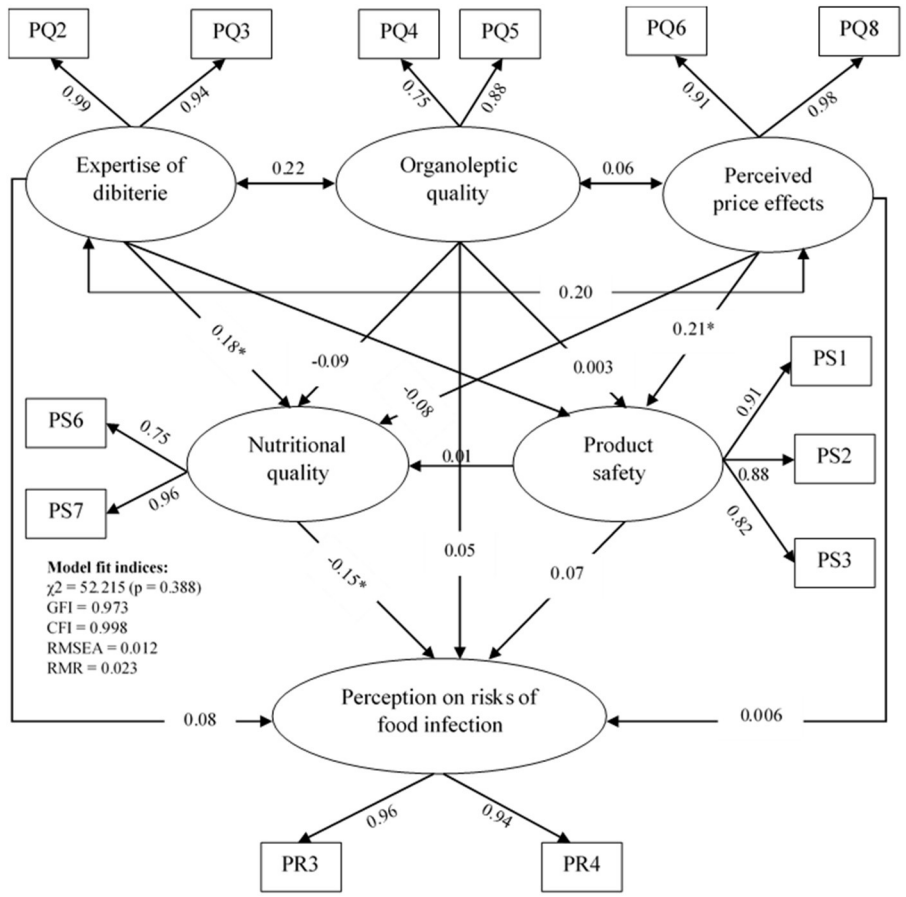

FIGURE 2 | Estimates of the final standardized model of the relationships between the latent variables of the perception on the quality, the perception on the safety of dibiterie meat, and the perception on the risks of food infection (PQ, Perception on the quality; PS, Perception on the safety; PR, Perception on the risks) ($n = 291$). *The value of standardized coefficients that are significant.

a source of lower profit for the seller. The words below illustrate these statements:

> "*Goat meat gives power, especially the testicles give men sexual power. Moreover, it is said that the men who work in the slaughterhouse (SERAS) love girls, this is due to the meat they consume every day*." FGD, woman consuming dibiterie meat, Pikine.
>
> "*Meat from young animal is more useful than meat from old animal, it is more productive, it gives you strength. That is why the Moor does not eat the meat of an old beef or an old sheep. He eats lamb or goat meat*." FGD, male consumer of dibiterie meat, Pikine.
>
> "*In a dibiterie, you have to sell lamb meat, because it is more tender. If you sell meat from adult mutton, it is tough and if a customer eats it, he will not want to come back in your dibiterie. Therefore, there will be a double loss: the non-profit because you are going to buy the sheep and you are not going to benefit, but also it means that the customer will not come back anymore*." Semi-structured interview with a dibiterie tenant in Pikine.

Consumption of dibiterie meat is also incited by social pressure and the expertise of the dibiterie. Indeed, social pressure, affinity with the seller, and the renown or expertise of the dibiterie are the incentives for buying and consuming dibiterie meat. These different factors are described below by the different actors surveyed.

> "*Sometimes my wife tells me she wants meat so that I go to a dibiterie to buy braised meat*." FGD, male consumer of dibiterie meat, Pikine.
>
> "*… yet I left dibiterie near my workplace, but I came here because it is my favourite dibiterie, because the salesperson masters his activity, also he is open and warm*." FGD, male consumer of dibiterie meat, Pikine.
>
> "*The communication or the publicity which one makes of me makes me gain customers. So much so that the other sellers of the dibiterie meat think that I wear Talisman; but the secret is at the base linked to my knowledge*." Semi-structured interview with a dibiterie tenant in Pikine.

Representation of the Risks Associated With the Consumption of Dibiterie Meat

According to the consumers of dibiterie meat surveyed, adult beef, cow and mutton are sources of non-communicable

diseases, including hypertension and hypotension. The following comments from a consumer consolidate this argument:

> "*Eating old mutton or beef is not good for your health. It causes hypertension or hypotension. That is why when I go to a dibiterie I always ask for lamb meat. If a dibiterie doesn't make lamb, I don't buy there*." FGD, male consumer of dibiterie meat, Pikine.

For those surveyed, hanging meat in the open air in dibiteries does not constitute a risk for the consumer. It allows the buyer, on the other hand, to assess the quality (freshness) of the meat. In fact, according to them, the cooking temperature of meat and faith in God help eliminate pathogenic microorganisms in meat and protect the consumer. The various comments below from customers describe this finding:

> "*… of course, the meat is hanging in the open air, but it allows me to know if the meat is still good and has not lasted too long. In addition, it is the fire that kills germs, every germ dies with fire, microbes cannot withstand 37°C*." FGD, woman consuming dibiteries meat, Pikine.
>
> "*At Thié, it's in the open air, but when a meat is braised, it will drive out germs, but it is God who protects us. We must pronounce the name of God while eating, especially as a Muslim. You surrender to God. You have to be positive in matters of food. We believe in God and we have confidence in him, even a poisoned diet, we will say Bismillah*." FGD, male consumer of dibiterie meat, Pikine.

In addition, the consumers investigated are aware of the health risks that clandestine slaughtering can engender for human health. Indeed, they argue that dibiterie meat from illegal slaughter is not safe for human consumption because of the diseases that humans can contract through animal products. This statement is described through the comments below from a consumer:

> "*I have my special dibiterie, the meat sold there comes from the slaughterhouse. I don't buy from dibiteries that slaughter animals illegally. Because someone can sell a sick sheep to a dibiterie and if you eat this meat, you will get sick too. But at the slaughterhouse there is more security with a vet's stamp. I vigil over the place where the animal is slaughtered. I don't trust the others*." FGD, woman consuming dibiterie meat, Pikine.

DISCUSSION

The present study has shown that consumers of dibiterie meat can be classified into three groups according to their level of perception of quality and safety, including low, medium, and high perception. More than half of the consumers surveyed (70%) had medium perception on the quality and safety of dibiterie meat, while individuals with low and high perceptions each represent only 15% of the whole participants. This low proportion of consumers who highly perceive the quality and safety of dibiterie meat may be linked to the difficulty of accessing information on the product that can be used to assess its quality. Indeed, the study showed that consumers rely mainly on the attributes of the experienced quality (taste), extrinsic quality linked to the production environment (dibiterie hygiene, salesperson' expertise, dibiterie renown, and name of the dibiterie), and belief quality (rich in vitamins) to assess the quality of dibiterie meat. According to Grunert (43), when buying and consuming a food product, consumers select, organize, and interpret information for immediate decision-making. Thus, the purchase decision is directly linked to the stimuli available to the consumer before a purchase (26). In addition, faced with the multiple decisions that must be made, most of the indicators that consumers look for in food products are characteristics of experience or credence (belief) that are unknown at the time of purchase (43). Consumers therefore try to reduce this uncertainty by drawing on their own past experience and on information provided by sellers and, to a lesser extent, from the third parties. The exact aspect of this information gathering process and how it leads to decisions depends on the retail environment in which the purchases take place (44). Thus, the ability to assess quality may first and foremost be conditioned by the ability of consumers to read and interpret information on verifiable qualitative attributes (45). Therefore, higher skill levels may lead to more information seeking and better buying results, but that information seeking in some cases can also increase perceived risk and decrease enjoyment and satisfaction (44).

Compared to the reference group (medium perception), the factors associated with low consumer perception on the quality and safety of dibiterie meat were income and food expenditure. Indeed, the income of between 100,000 and 150,000 FCFA/month positively affects the low perception on the quality and safety of dibiterie meat. This suggests that people with a monthly income between 100,000 and 150,000 FCFA have a low perception on the quality and safety of dibiterie meat. Moreover, compared to the reference, food expenses of between 50,000 and 75,000 FCFA/month negatively influence the low perception. Thus, people with food expenses of between 50,000 and 75,000 FCFA/month have a lower tendency to weakly perceive the quality and safety of dibiterie meat. In summary, people belonging to the middle- or upper-income class and spending more on their food have a lower tendency to weakly perceive the quality of dibiterie meat. Therefore, we can deduce the importance of the price's factor in assessing the quality and safety of dibiterie meat. This suggests that, in the market place, consumers are sensitive to the price of dibiterie meat and are willing to support the transaction costs associated with the availability and access to information on the attributes of quality and safety. Furthermore, Mamine et al. (45) point out that the relative ability of consumers to perceive information on quality attributes is sometimes at the root of the controversies that characterize their purchasing rationality. Consequently, the latter use trust and reputation to reduce these costs of quality assessment which also follows a controversial schema (45).

The study also showed that compared to the reference group (medium perception), the high perception on the quality and safety of dibiterie meat is negatively associated with the age between 16 and 20 years. In other words, people between 16 and 20 years old do not highly perceive the quality and safety of dibiterie meat. Furthermore, unlike the low perception, high perception is not significantly associated with income, but rather

with food expenditure, and the more people have food expenses of between 75,000 and 100,000 FCFA/month, the more they tend to have a high perception on the quality and safety of dibiterie meat. These results can be explained by the fact that young people are, on the one hand, less concerned with issues related to food quality and safety and, on the other hand, have less skills or experience to identify and interpret the available information on the quality and safety attributes. In contrast, people with high food expenditure demand much more from the quality and safety of the food products they consume. As such, it suggests that they are more willing to research and afford the price necessary to gain access to information enabling them to assess the quality of the products purchased.

We found that the perceived price effects had a significant and positive relationship with the perception of product safety, but had no direct impact on the perception on the risk of food infection. In other words, the perceived price effects increase the perception on the safety of dibiterie meat. This suggests that consumers believe that expensive dibiterie meat provides assurance on the safety of the product. These results are in line with the study by Orou Seko et al. (46) carried out among consumers within the dibiteries. These authors found that consumers surveyed in outlets were willing to pay an extra of $0.5 to $0.84 over the usual selling price of dibiterie meat (between $8.01 and $8.16 per kilogram on average) in order to improve the quality of the product (46). This demonstrates the link between the price and the sanitary quality of food products already demonstrated by several authors in the literature (14, 15, 43, 44, 47–51).

The expertise of the dibiterie indirectly impacted the perception on the risks of food infection through the variable linked to the perception on the nutritional quality of the product. However, the direct path had no effect on the perceived risks of food infection associated with the consumption of dibiterie meat. Indeed, the results showed that the expertise of the dibiterie increases the perception on the nutritional quality of the dibiterie meat, which, in turn, decreases the perceived risks of food infection. This suggests that consumers of dibiterie meat are aware that the expertise (preparation of the meat) that gives the dibiterie renown could lead to an improvement in the nutritional quality of the dibiterie meat and thus reduce consumer perception on the risks of food infection. It also means that faced with the expertise of dibiterie, consumers pay much more attention to the nutritional quality of the meat than to the risk of food infection. Several studies have shown that cooking methods have significant impacts on the nutritional and sanitary quality of the foodstuffs. Indeed, cooking methods are used to improve the microbiological quality of food, destroy various toxins and other contaminants, and, therefore, increase the safety and shelf life of food. In addition, they have greatly contributed to improving the organoleptic quality by generating the formation of commonly appreciated flavors and textures. Although the benefits of culinary processing are numerous and well-identified, it is obvious that cooking and preservation treatments also sometimes lead to a deterioration in the nutritional quality of foods. Among macronutrients, it is mainly proteins and lipids that are affected by heat treatment (52–56). An investigation on the impact of heat treatments (cooking on a traditional oven using wood fire or charcoal) on the nutritional quality of mutton in the different types of dibiteries (Senegalese, Hausa, and Moor) could be of great interest in providing adequate answers to this problem. This should lead to proposals for recommendations to consumers for better guidance on the choice of processed foods to consume and on the preferred cooking methods.

At the end, this study showed that 16% of consumers strongly perceive the quality and safety of dibiterie meat. In addition, the strong perception of the consumers on the quality and safety of dibiterie meat has been positively associated with their monthly food expenditure, while their age explained it negatively. Furthermore, among the latent variables identified, the perceived price effect and the dibiteries' expertise were positively related to the perception on the safety and the perception on the nutritional quality of the product. The nutritional quality of the product perceived by consumers had negatively impacted their perceived risks of food infection. This study suggests the strengthening of hygiene standards in dibiteries and the awareness of consumers, especially young people, about the potential health risks associated with the consumption of dibiterie meat.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Research Ethics Committee of the University Cheikh Anta Diop (No. 0318/2018/CER/UCAD). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

MO, WO, NL, and BB: conceptualization, methodology, visualization, and writing—review and editing. MO: data curation, formal analysis, and writing—original draft. NL: investigation. BB: project administration, resources, and validation. WO: supervision. All authors have read and agreed to the published version of the manuscript.

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Unpacking the Theory Behind One Health Food Safety Programs: A Vietnam Case Study

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Many One Health programs are inherently complex, characterized by multiple perspectives from multiple sectors, delivery across various scales, and a focus on complex problems at the convergence of people, animals, and the environment. This complexity makes them difficult to conceptualize, requiring frameworks to organize the different program components. Evaluation frameworks that unpack the sequence of events linking program activities to outcomes (e.g., Theory of Change) and track outcomes (e.g., Outcome Mapping) show promise in supporting the development of One Health programs. While widely used in international development and health contexts, there has been little reflection on the use of Theory of Change and Outcome Mapping within One Health efforts. This paper reflects on the process of applying these frameworks to conceptualize a One Health food safety program in Vietnam. We find Theory of Change fostered the characterization of a change pathway toward safer pork, while Outcome Mapping kept us informed of where along the change pathway we were. One Health programs considering evaluation frameworks should adopt elements that make sense to them, be intentional about co-designing the evaluation, and view evaluation as a process, not a product.

Keywords: One Health, food safety, Vietnam, theory of change, outcome mapping, program evaluation

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INTRODUCTION

The interaction between humans, live animals for sale, and food products in informal and open-air food markets creates risks for food safety and emerging infectious diseases (1). COVID-19—potentially emerging from markets that sold animals—reinforces the need to prepare for the potential spillover of infections from animal and animal products to humans (2). In drawing attention to multi-disciplinary, multi-sectoral action, the One Health approach is considered a promising strategy to address food safety, animal, and environmental threats (3–5). However, the focus of One Health programs on complex problems at the convergence of people, animals, and the environment, along with the multiple perspectives from different disciplines and sectors, characterize many One Health programs as complex (6, 7).

This complexity makes One Health programs difficult to conceptualize, requiring frameworks to organize the various components of One Health programs (8). Understanding a program's underlying theory is a promising strategy for supporting the planning, implementation, and evaluation of programs, particularly those with multiple interacting components (9, 10). In response to the need to support learning within complex development programming, Theory of Change (ToC) and Outcome Mapping (OM) are receiving growing attention (11, 12). ToC is a tool often used in evaluation for exploring change, how it happens, and why, viewing change processes as dynamic, interlinked, and non-linear (13). OM is an approach to planning, monitoring, *and* evaluation that focuses on social change, placing development actors at the core of its processes (14). Both represent a paradigm shift away from conventional evaluation by focusing attention on what must change *before* considering how change can be achieved.

ToC originated in the context of social change whereby it was difficult to evaluate social change programs that were not clear about what they set out to do and how (15). As its name suggests, ToC is a theory of how and why a program works. While the understanding of ToC has evolved in recent years, ToC is commonly viewed as a critical reflection on a program's strategy, context, and outcomes (16). Increasingly, ToCs are used to facilitate sense-making at regular intervals and are often updated in adaptive programs as new information is learned (17, 18). In contrast, OM is a well-defined approach to evaluation that was adapted from "outcome engineering" (19). OM is designed to support evaluation practitioners in assessing the contributions made by development programs to the achievement of outcomes rather than impact. OM focuses on factors and actors within the program's direct sphere of influence (14).

The shared emphasis on outcomes suggests a common ground for ToC and OM to work together. For example, ToC might provide a shared roadmap toward systems change and highlight potential areas for monitoring and evaluation. However, ToC does not tell us what indicators to monitor, who will monitor them, and when to collect data. OM could facilitate testing and validation of the ToC by analyzing the behavioral changes and interrelationships of development actors. Yet, the operationalization of OM is often resource-intensive, requiring substantial adaptations based on organizational capacity (20). Combining ToC and OM might overcome critiques of each tool and thus be considered a productive endeavor to improve the evaluation of complex interventions.

Although combining the two shows promise in addressing complexity, there are some differences in the theoretical underpinnings between ToC and OM. ToC was developed in response to difficulties in evaluating complex social change programs, calling for the articulation and testing of assumptions underlying change processes (13). Also originating in the context of social change, OM assumes that development happens through behavioral change and that sustainable change requires meaningful engagement with key actors. Given their slightly different histories and research traditions, ToC and OM have developed different practices; ToC focuses on developing a rich description and visual representation of the program theory whereas OM is primarily concerned with understanding or 'mapping' behavioral outcomes. While both tools are emerging in development evaluation, there is a paucity of reflective practice on the use of ToC and OM together, particularly in dynamic, low-resource settings (21).

Considering the need for frameworks guiding the conceptualization of One Health programs, and the promising role of ToC and OM, this paper reflects on the experiences of constructing ToC and OM to inform a One Health program. Specifically, the objectives of this paper are to (1) describe how ToC and OM frameworks can be applied to support the monitoring and evaluation of a One Health food safety program in Vietnam; and, (2) reflect on the process, challenges, and opportunities of developing these frameworks. In doing so, we provide lessons in developing One Health food safety programs in dynamic, low-resource settings.

Context: Addressing Pork Food Safety in Vietnam

We focus on the 'Market-based approaches to improving the safety of pork in Vietnam' (SafePORK) program to explore the use of a combined ToC and OM. SafePORK is a 5-year program funded by the Australian Center for International Agricultural Research and implemented by the International Livestock Research Institute, Vietnam National University of Agriculture, Hanoi University of Public Health, and national (National Institute of Animal Sciences) and international partners (University of Sydney). The development of SafePORK was motivated by a growing concern for food safety, one of the most pressing issues among people in Vietnam (22). In particular, the safety of pork is a major concern as pork is the most widely consumed animal source food in Vietnam (23, 24). Pork safety is a shared responsibility among many actors along the pork value chain, making risk management for pork safety a complex challenge. SafePORK operates in several areas of Vietnam (Hanoi, Hoa Binh province, Hung Yen province, and Nghe An province). Applying a One Health approach, SafePORK aims to reduce the burden of foodborne disease in the informal, emerging, and niche markets of Vietnam.

SafePORK can be considered a complex program, characterized by a plurality of stakeholder perspectives and multiple interacting components (25). The research team is comprised of veterinarians, medical doctors, public health experts, farming systems experts, and agricultural economists. They work closely with actors along the pork value chain (e.g., farmers, slaughterhouse workers, wet market retailers, and consumers) and other decision-making partners (e.g., local authorities). Research and development activities of SafePORK often overlap and include generating evidence on feasible approaches; identifying, developing, and piloting light-touch interventions; and, building capacity to manage food safety risks among government partners, private sector actors, journalists, and pork value chain actors. One of the core objectives (number

BOX 1 | Objectives and activities of the SafePORK program.

ACIAR Project No. LPS/2016/143
Duration: October 2018 to June 2022
Budget: A$2 Million
Objective 1: Generate evidence on the efficacy, feasibility, and reach of current approaches for improving pork safety in Vietnam. Key activities include conducting a rapid value chain assessment, and developing and applying a food safety performance tool.
Objective 2: Develop light-touch, incentive-based approaches to food safety. Key activities include selecting five value chains for piloting interventions, establishing a food safety baseline for the selected value chains, conducting participatory research to develop interventions, implementing 'best bet' interventions, and evaluating outcomes.
Objective 3: Develop a Theory of Change for market-based interventions. Key activities include forming a Food Safety Stakeholder Group, developing a theory of change, and revisiting the theory of change periodically.
Objective 4: Support strategies for benefits sharing among men and women in the pig value chain. Key activities include providing gender training, conducting gender analysis of constraints to adopting interventions, and integrating gender considerations into all activities.
Objective 5: Build capacity in understanding and managing food safety risks. Key activities include identifying key beneficiaries, providing risk communication training to beneficiaries, disseminating research findings, and evaluating effective communication strategies.

three) of SafePORK is to develop a roadmap showing how, why, and in what context SafePORK leads to safer food (**Box 1**).

METHODS

Rationale for Using ToC and OM

Given the complexity of the food safety challenge in Vietnam, the engagement of multiple perspectives characteristic of One Health approaches, and the need for learning support throughout the SafePORK program, we were interested in a framework that was responsive to dynamic, real-world environments. We wanted to systematically capture and learn from our outcomes to inform adaptations to the program. As everyone has different ideas, hypotheses, and assumptions ("theories") about how change happens, going through a ToC process can help make these theories explicit. We used ToC to establish a shared roadmap toward change and identify potential areas for monitoring and evaluation. A ToC, however, does not tell us how to assess change; we combined ToC with tools offered by OM to support SafePORK in not only learning about its change process but also in measuring it. OM is often considered well-suited to assess programs implemented under complexity in which multiple influences make it difficult to predict what will happen as a program proceeds (26). We used OM to help the team be specific about the actors SafePORK intends to work with, the behavioral changes it hopes to see, and the strategies needed to achieve such changes. Furthermore, we used OM as a framework to monitor outcomes.

Theory of Change Development and Use

We developed a ToC following advice from several guidance documents (27–29) along with consultations with the team. Often absent from ToC guidance documents is the focus on systems change, yet, capturing systems change is particularly important for food safety programs that influence (and are influenced by) food systems (30). Our adapted 5-step ToC process is iterative, cyclical, and reflective, involving: (1) contextual analysis; (2) identifying the goal; (3) working backward to identify what changes must occur to reach the goal; (4) working forward to identify how the program will contribute to changes; and, (5) stating assumptions underlying change processes (**Figure 1**). By starting with an overview of potential long-term outcomes at the end of the program (2022), a focus is placed on the bigger picture of systems change. Proposed SafePORK contributions (from 2017 onwards) are added to the change pathway only after systems change is envisioned.

To operationalize the methodological framework for developing a ToC, a full-day workshop was conducted with 12 SafePORK researchers (seven women and five men). The facilitator (SL) described the ToC approach using examples and then asked participants to undertake an exercise following the 5-step process. As SafePORK works extensively with several actors along the pork value chain, participants agreed to create separate actor-based ToCs while acknowledging that ToCs might be combined into one comprehensive ToC later. Participants were split randomly into two teams; one worked on slaughterhouse workers and retailers while another worked on consumers and policymakers. Toward the end of the workshop, participants were asked to reflect on the challenges and opportunities of developing a ToC.

Outcome Mapping Development and Use

OM is a three-stage process of intentional design, outcome and performance monitoring, and evaluation planning (14). In the first stage, stakeholders create a vision of desired behavioral outcomes and outline strategies to be used in achieving such outcomes. The second stage provides a framework for monitoring progress toward changes identified in stage one. The third stage provides a framework for identifying evaluation priorities and conducting an evaluation. To design SafePORK's monitoring and evaluation, we adapted OM; we focused on intentional design to build on the ToC (**Figure 2**).

To operationalize OM, we convened a half-day workshop with SafePORK researchers (5 women and 4 men). The facilitator (SL) explained the theory of OM and provided examples of OM in practice. As most team members were already familiar with OM through the previous phase of SafePORK (PigRisk program; ACIAR LPS/2010/047; 2012-2017), we worked together quickly through the initial OM steps (i.e., drafting

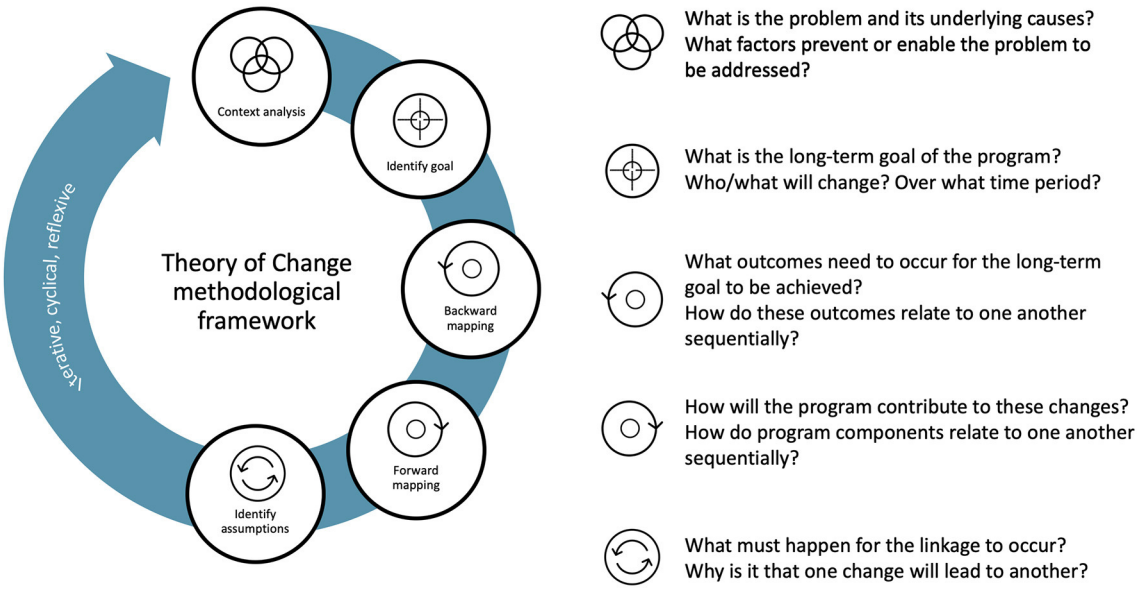

FIGURE 1 | Theory of change methodological framework and guiding questions.

FIGURE 2 | Outcome mapping methodological framework and guiding questions.

the vision and mission statement). More time was spent focusing on boundary partners, outcome challenges, and progress markers often considered the "essence of OM" (31). Specifically, participants were split randomly into two teams to explore boundary partners, outcome challenges, progress markers, and strategies, and how these relate to SafePORK's vision and mission. Toward the end of the workshop, teams planned for the outcome monitoring.

RESULTS

Hypothesizing the Program Theory

The resulting ToC in **Figure 3** visually describes the presumed mechanisms of change occurring within the food system in Vietnam. Here, we expand on the ToC by narratively describing the pathway as well as assumptions and context underlying change. The overall goal of SafePORK is to reduce the burden of food-borne disease in traditional, emerging, and niche markets

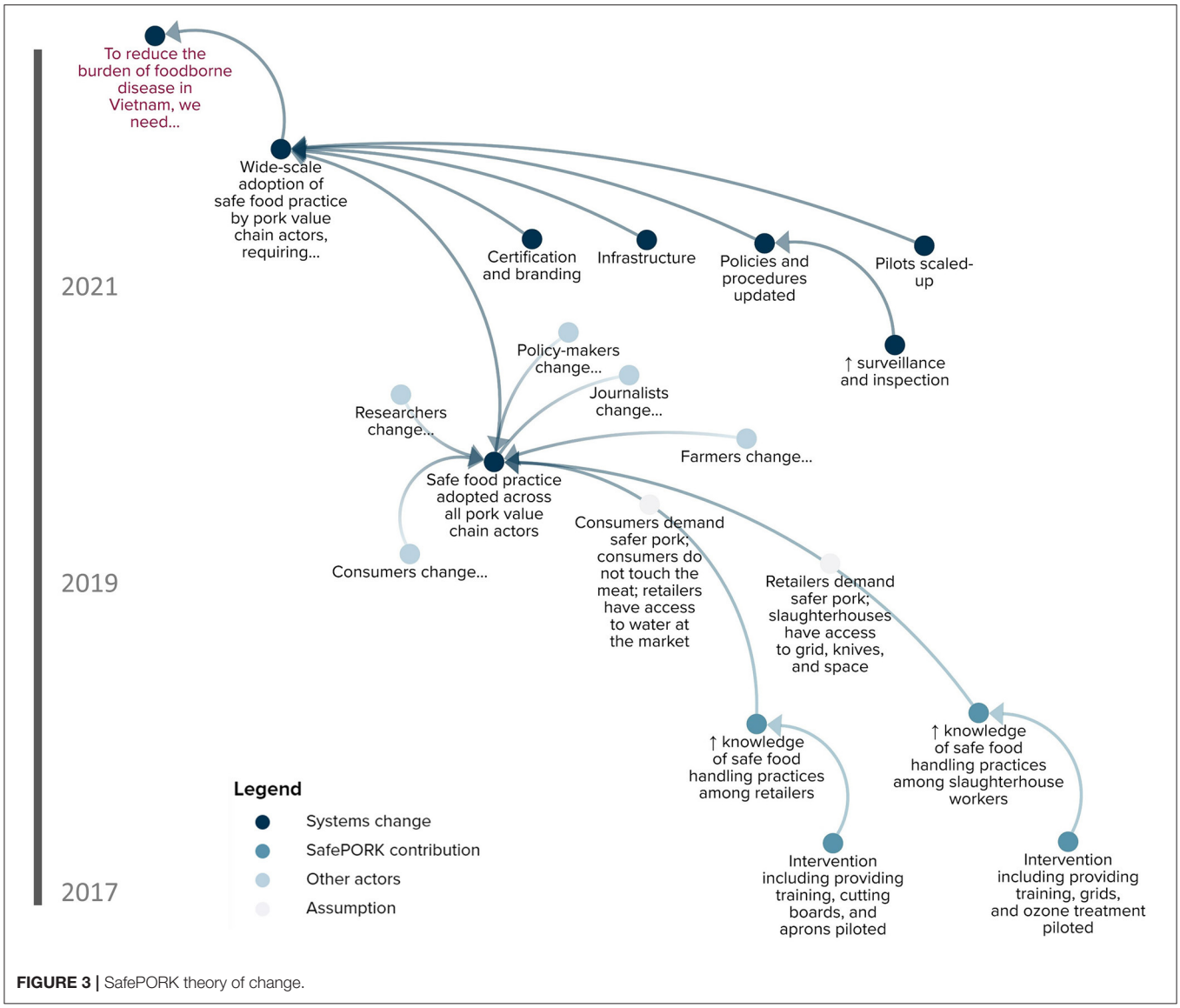

FIGURE 3 | SafePORK theory of change.

of Vietnam. To achieve this goal, SafePORK proposes that wide-scale adoption of safe food practices among all pork value chain actors is needed. Two pre-conditions are required to achieve this wide-scale adoption: (1) small-scale adoption of safe food practice and (2) updated policies.

According to SafePORK researchers, the identification of cost-effective practices is important for supporting small-scale adoption of safe food practices among women and men. SafePORK intends to contribute to this outcome by piloting light-touch incentive-based interventions, training, and communication along the pork value chain. Several assumptions underlie the causal link between SafePORK activities and improved safe food practices, such as retailers', slaughterhouses', and consumers' demand safer pork. Furthermore, safe food practices need to be supported by broader environmental factors including slaughterhouse and market infrastructure, food safety procedures and enforcement, and certification and branding, which may be indirectly influenced by SafePORK.

Secondly, researchers emphasized that policy-makers should strengthen policies, support the scaling-up of SafePORK pilots, develop a model for small-scale slaughterhouses, improve surveillance and inspection, and increase the budget for food safety interventions. SafePORK intends to influence these actions by presenting evidence from pilot interventions to policymakers through policy brief workshops and study tours. At the provincial level, for example, SafePORK is engaging the sub-Department of Animal Health in Hung Yen in dialogue surrounding the slaughterhouse intervention model. There are several assumptions behind this causal link, such as policy-makers must be interested in improving food safety. While this assumption may seem obvious, the experiences of SafePORK

(and PigRISK) demonstrate that buy-in from policy-makers is essential and must be fostered for interventions to succeed.

Researchers also considered the social and physical environments to be important factors underlying the success of SafePORK. For example, Hung Yen is an appropriate province to implement interventions given its high pig production, proximity to the capital city (Hanoi), and room for improvement of hygienic practices. In Hanoi, greater awareness of food-borne diseases, higher income, and generally stronger infrastructure make Hanoi a conducive environment to conduct food safety interventions. Interventions also need to consider who participates in and benefits from efforts aiming to improve food safety and the different roles and responsibilities of women and men. For example, slaughtering is mostly done by men while retailing and purchasing are mostly done by women, providing opportunities for targeted risk management.

Planning for Monitoring and Evaluation Through Outcome Mapping

The articulated program theory provided us with a starting point for planning evaluation activities through outcome mapping's intentional design stage. According to SafePORK researchers, the vision of SafePORK is to improve public health by reducing the burden of food-borne disease in traditional, emerging, and niche markets of Vietnam. Its mission is to develop and test market-based, light-touch, and incentive-based interventions. While SafePORK interacts with many boundary partners with a critical role in ensuring food safety, program monitoring and evaluation will focus primarily on slaughterhouse workers and retailers. We consider slaughterhouse workers and retailers to be within SafePORK's direct 'sphere of influence' whereas other value chain actors are within SafePORK's indirect 'sphere of interest' (14). The main outcome challenge for direct partners is to maintain more hygienic pork handling practices taught in SafePORK training. Progression toward this outcome will be measured by indicators ranging from agreeing to take part in identifying promising interventions to maintaining practice change (**Figure 4**).

Researchers agreed that the progress of boundary partners toward the achievement of the outcome challenge will be measured on an ongoing, real-time basis. Monitoring journals provided by OM will be used to guide this process. The outcome journal will track the behavioral changes of partners using progress markers whereas the strategy journal will document the activities conducted to achieve outcomes. Several focal points from the SafePORK team will contribute to one shared journal integrating outcomes and strategies. Specifically, the focal points will document (1) activities/strategies implemented, including with whom, where, and when; (2) reflections on what changes occurred, what worked well, and what could be done better; and, (3) and share pictures of before and after. The collected information will be used to inform adaptations to interventions and provide evidence for the final evaluation.

From our ongoing monitoring efforts, we are starting to see behavioral changes during implementation (in some areas and not others), informing adaptations to the intervention. For example, at a slaughterhouse in Hung Yen, we are seeing the provided grid and tables being used during carcass handling. Importantly, some tables were co-invested by the slaughterhouse owner, highlighting the slaughterhouse owner's interest in the program. We are also seeing better separations between clean and dirty areas. However, sometimes knives are not properly cleaned after use and in some cases are put on the floor. The team makes regular visits to the slaughterhouse to encourage hygienic practices. At the traditional wet markets, we are seeing retailers now using separate cutting boards for raw meat and cooked meat. However, many retailers prefer wooden boards because they are better for chopping bones. To address this challenge, the program co-invested in wooden cutting boards with retailers.

DISCUSSION

This paper describes the experiences of researchers in applying evaluation frameworks to conceptualize a One Health program aiming to improve food safety in Vietnam. We began applying ToC and OM during the formative stages of the program design, enabling us to better anticipate, monitor, and track outcomes early on in the program. We noticed some overlaps and differences between the two outcome-based evaluation frameworks. For example, a ToC focuses on the articulation of a goal, the causal pathways linking short- and medium-term changes to the long-term goal, and the strategies used to achieve outcomes; these steps appear to be consistent with the intentional design stage of OM. However, one notable difference is that ToC emphasizes the need to explicitly define the underlying assumptions behind the change pathways and the contextual factors that influence programming, elements that are typically unexplored in OM (32). Given this complementarity, we agree that combining OM and ToC can be a productive endeavor to support the development of complex programs generally (9, 21, 33) and for One Health programs specifically (9).

What Is the Promise of Combining ToC and OM?

Combining ToC and OM can address some criticisms associated with each approach. For example, ToCs can sometimes be seen as vague, generic, and simplistic (34). This case study demonstrated that developing progress markers for certain outcome pathways can provide further detail into outcome indicators that are typically missing in ToCs. Conversely, OM is critiqued for neglecting systems thinking by focusing solely on outcomes as behavioral change (35). Yet, OM is generally considered to align with select concepts of systems thinking. For example, *interrelationships* are acknowledged when 'outcomes' are defined as patterns of behavior and interactions among stakeholders; *perspectives* of specific actors are accounted for when setting 'outcome challenges' for specific actors; and, *boundaries* are considered when selecting 'boundary partners', including some actors and excluding others. We consider the interrelationships between stakeholders to be particularly

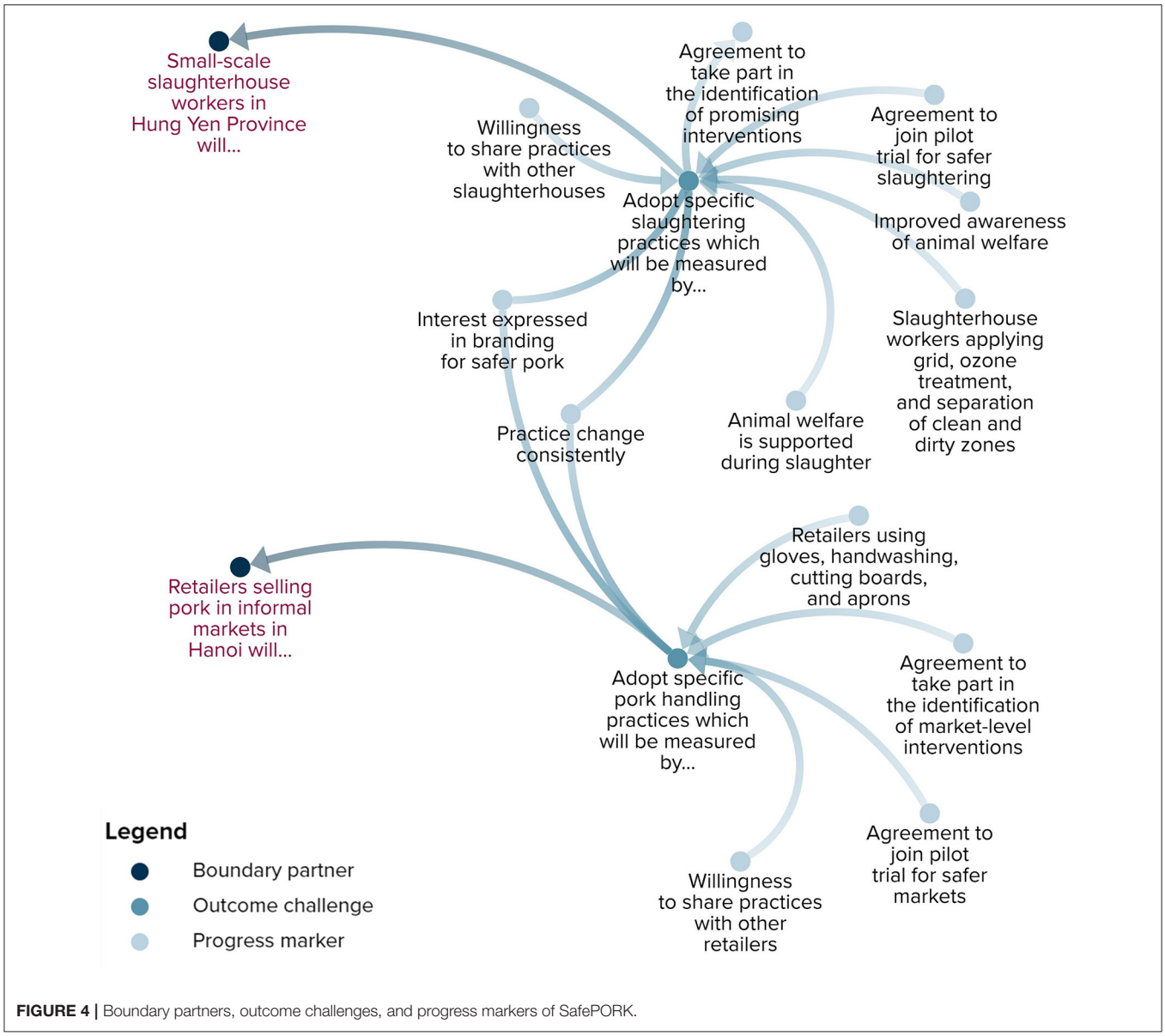

FIGURE 4 | Boundary partners, outcome challenges, and progress markers of SafePORK.

important to monitor; in previous (e.g., PigRISK) and current phases of the program, we considered our partnership as a separate unit of analysis, collecting and sharing reflections about the partnership to ensure various actors operate smoothly as a functioning team (36). Furthermore, because of OM's orientation toward understanding complex and non-linear relationships between different actors that can shape a program, OM is often understood as a complexity-sensitive method (17, 26). To address the critique that OM lacks systems thinking, mapping systems change using a ToC can help to illuminate how boundary partners are influenced by (and are situated within) a social-political system. Furthermore, the progress markers of "expect to see," "like to see," and "love to see" reflect the direct response to program inputs and not necessarily a temporal sequence (37); mapping outcomes and their inter-relations in a ToC enables a stronger understanding of when outcomes might occur.

ToC Then OM, or OM Then ToC: Does Order Matter?

When comparing our process in combining ToC and OM to other programs operating in low-resource settings, we find a variety of processes. We used ToC as a starting point for OM; we kept the findings from the two tools separated to allow for cross-comparisons and to maximize the potential of both tools. In Balls and Nurova, a ToC was created at the program design stage to guide the monitoring and evaluation of sanitation and hygiene research projects in Zambia, Kenya, Malawi, and Tanzania (38). Their ToC illustrated how outcomes will be monitored through OM progress markers, suggesting

an effort to combine ToC and OM findings. In other studies, OM was conducted first. For example, OM and ToC were used to encourage 12 non-governmental organizations working on sustainable forest management in Papua New Guinea to align their efforts (39); the ToC was created after the development of OM progress markers to help visualize the relationships between drafted outcome statements. Similarly, in an evaluation of a disaster risk reduction network in the Asia-Pacific region, OM was used to visualize the relationship among stakeholders, the desired behavioral changes, and progress markers; then, ToC was used to identify and test assumptions behind such changes (21). We see the variation in ToC/OM combinations as a strength and a response to the different needs and priorities of programs. We encourage evaluation practitioners to be explicit about their approach in combining the two and to reflect on implications.

Where Do Conceptual Gaps Remain?

The identification of assumptions underlying the change processes was not found to be particularly difficult, as typically reported in ToC case studies (34); however, one participant emphasized some assumptions were large and require dedicated interventions to address them. A big assumption, for example, is that SafePORK can contribute to the development of food safety certification. Yet, achieving certification is challenging due to short project timelines and the lack of consumer trust surrounding certifications (40). While evaluators have provided clarity on what assumptions are and how to identify them (41, 42), specific guidance is required on whether certain assumptions are better considered as a step along the change pathway or as an assumption underlying the change. In terms of outcome monitoring, we are starting to accumulate a lot of journal entries but struggle in presenting this data in a meaningful way. Some practical examples from the literature visualizing outcome monitoring data would be helpful.

Lessons Learned

Three key lessons for evaluation practitioners emerged that are applicable when planning the evaluation of programs operating in dynamic, low-resource settings:

(1) *Adapt tools that make sense to the program and context*. Experimental designs are typically prioritized in evaluations of food safety interventions (43). However, the value of these designs can be limited in environments characterized by complexity. In such cases, this study suggests alternative approaches can be used. We demonstrate how ToC and OM coming from the outcome-based evaluation can be used together toward food safety. For example, the experiences captured in this study show that ToC illuminated potential change pathways while OM, particularly the intention design stage, provided a framework for monitoring progress toward change. These contributions might not have been possible using conventional approaches to evaluation because of the formative nature of SafePORK.

(2) *Be intentional with co-designing the evaluation*. We stress the importance of being intentional about designing the outcome monitoring system. This means providing space and time for team members to come together and think about how the elements of ToC and OM might be combined. It also means working closely with focal points or key members who will collect and share the data. For SafePORK, two focal points made journal entries after each routine visit to the field, which reduced the need for additional human resources and field visits. That said, monitoring outcomes is an additional responsibility for focal points that need to be supported through ongoing training, incentives, and data quality management.

(3) *View evaluation as a process, not a product*. While our team was familiar with OM, developing a ToC was new for some members. We intended to use ToC as a starting point for outcome mapping. The developed change pathway helped to visualize the sequences of and relationships between outcomes. Because it was the first time the team conducted a ToC, we did not expect to have a strong, initial ToC by the end of a one-day workshop. It helped that researchers were made aware of workshop objectives well in advance, creating an environment to participate fully in the exercises. However, when we shared the ToC in a SafePORK planning meeting, it was clear that the ToC could have been further detailed. For example, a researcher who was not able to make it to the workshop suggested that the outcomes are somewhat vague and could be further specified. If we were to do this process again, we would circulate the ToC earlier and on a routine basis. However, we view the ToC as a process, not a product; our next step is to share this initial ToC with our boundary partners for revision, as suggested in Mayne (44). We will continue updating our change pathways as the program proceeds and as new information from outcome monitoring is gained.

Limitations

We note several limitations to our study. Similar to the experiences reported in Taye et al. (20), we find the progress markers developed may not have been appropriate or realistic. For instance, progress markers for slaughterhouse workers and pork retailers such as "agreement to take part in intervention" might be too simplistic, while "consistent practice change" might be beyond the scope of the project. And like the experiences reported in Balls and Nurova (38), we found some preliminary data from monitoring journals to be messy and inconsistent. Continued reflections by evaluators, researchers, and participants on the development and use of outcome mapping tools would provide important insights to improve evaluation practice. Furthermore, because SafePORK is ongoing, our ToC is a 'work in progress'; we will keep in mind design considerations, such as a better description of connections (45), to ensure our ToC is testable. Finally, due to resource constraints, our ToC and OM were based on researcher perspectives only. Developing ToC and OM with multiple stakeholder groups along the

pork value chain might have led to a more nuanced ToC and OM and a better understanding of priorities to be included. However, through active participation in research and intervention design, stakeholders indirectly contributed to these evaluation activities.

CONCLUSION

The challenges and opportunities of frameworks guiding the conceptualization of One Health programs are largely absent from the literature. This study critically reflects on our experiences as researchers in combining ToC and OM during the initial design stages of a One Health food safety program in Vietnam. For the SafePORK program, ToC enabled the scrutinizing of change pathways and the context and assumptions in which change occurs. Equally important, OM provided a framework to help plan and monitor strategies toward and outcomes of safer food. We echo the recommendation in Pasanen et al. when designing outcome monitoring systems: "it doesn't need to be complicated" [(46), p. 30]. Using outcome journals of OM, we are documenting the gradual changes toward steps in the change pathway identified by ToC. While our experiences in using ToC and OM are overall positive so far, we will continue revisiting, revising, and reflecting on our evaluation approach as the program proceeds, contributing to better understandings of pathways toward safer pork in Vietnam.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary files, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The study is a reflection of the authors' experiences in developing a program. No additional information from human participants was collected.

AUTHOR CONTRIBUTIONS

SL contributed to conceptualization, research, and writing. All authors read, commented, and agreed on the submitted manuscript.

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Use of a Participatory Method for Community-Based Brucellosis Control Design in Agro-Pastoral Areas in Tanzania

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Brucellosis is widespread in both humans and livestock in many developing countries. The authors have performed a series of epidemiological studies on brucellosis in agro-pastoral areas in Tanzania since 2015, with the aim of the disease control. Previously, the potential of a community-based brucellosis control initiative, which mainly consisted of the sale of cattle with experience of abortion and vaccinating calves, was assessed as being effective and acceptable based on a quantitative approach. This study was conducted to investigate the feasibility of community-based brucellosis control program using participatory rural appraisals (PRAs) and key-informant interviews. Four PRAs were performed together with livestock farmers and livestock and medical officers in 2017. In the PRAs, qualitative information related to risky behaviors for human infection, human brucellosis symptoms, willingness to sell cattle with experience of abortion, and willingness to pay for calf vaccination were collected, and a holistic approach for a community-based disease control project was planned. All of the communities were willing to implement disease control measures. To avoid human infection, education, especially for children, was proposed to change risky behaviors. The findings of this study showed that community-based disease control measures are promising.

Keywords: agro-pastoralist, brucellosis, disease control, participatory epidemiology, Tanzania

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INTRODUCTION

Brucellosis is a zoonotic disease of veterinary, public health and economic importance, especially in developing countries (1). In livestock, brucellosis results in reduced productivity through abortion, infertility and low milk production (2). Human brucellosis causes flu-like symptoms, including persistent and irregular fever, malaise, arthralgia and other constitutional symptoms, and results in high-cost treatment and loss of income due to loss of working time (3). In cattle, the disease can be transmitted through aborted fetus, placenta, milk and semen from infected animals (2). For human infection, consumption of unheated meat and dairy products and contact with infected animals are the main transmission routes (4).

Generally, zoonosis control can be achieved effectively by tackling animal reservoirs. Bovine brucellosis control activities consist of surveillance, control of movement, stamping out and vaccination. However, the implementation of these control measures has been poor in sub-Saharan countries (5). In Tanzania, where brucellosis is widespread in both animals and livestock keepers, the control of brucellosis by the national and/or local governments is unfeasible due to limited resources (6, 7). Since 2015, the authors have performed epidemiological research on brucellosis in cattle and humans in agro-pastoral areas in Morogoro region, Tanzania. Those quantitative studies revealed the endemic status of brucellosis in the cattle of the region, with the individual and herd level prevalences 7.0 and 44.4%, respectively (8, 9). Risk factor analysis revealed a strong association between abortion and brucellosis in cattle. In addition, a high willingness to pay 3,000 Tanzanian Shillings (∼1.3 USD) for calf *Brucella* vaccinations (89.6%) was observed among cattle farmers, indicating that community-based bovine brucellosis control is potentially feasible (9).

A qualitative research approach, referred to as participatory epidemiology (PE), has become an increasingly important area in epidemiology (10). The use of participatory rural appraisals (PRA) is one of the techniques used in PE and is widely used to collect and evaluate the opinions of a target group (11–13). The participatory approach overcomes the limitations of conventional epidemiological methods, such as high cost, complexity in logistics, and misinterpretation of quantitative information due to the researchers' lack of understanding of the local context (14, 15). Moreover, PRA is an effective method for not only collecting information, but also for ensuring stakeholders' participation in decision making (16). In the veterinary field, participatory methods have been widely used in community-based livestock projects in Africa and Asia since the 1980's (17). Since then, participatory approaches have been refined and subsequently integrated as a sub-discipline in the emerging field of veterinary epidemiology (10, 18).

The objective of the current study was to assess the potential of community-based disease control using PRA as a means of complimenting quantitative information obtained from conventional epidemiological studies.

MATERIALS AND METHODS

Four PRAs were conducted at the village offices of four agro-pastoral communities in the villages of Mvomero, Makuyu, Milama and Wami Sokoine in Mvomero District, Morogoro Region, Tanzania, between September and October 2017 (**Figure 1**). Quantitative brucellosis studies in cattle had been performed in the villages by the research team of this study (8, 9). The economy of the district is highly dependent upon agriculture. The main types of livestock raised in the villages are cattle, goats, sheep, pigs, donkeys and chickens. Most of the cattle farmers raise indigenous breeds using semi-extensive or extensive systems.

In addition to the research team, local administrative, veterinary, agriculture and medical officers were involved in administering the PRAs. The majority of participants in the PRAs were cattle farmers that were surveyed in our previous bovine brucellosis research conducted in 2016, as well as other cattle farmers (9). Women were encouraged to participate in the PRAs to ensure a gender-balanced view.

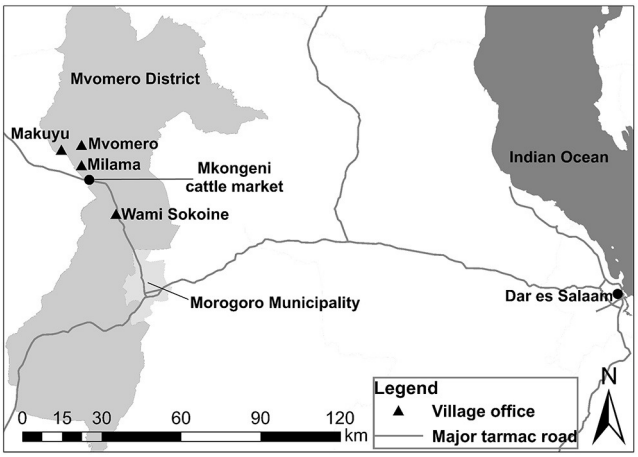

FIGURE 1 | Map showing the locations of the villages surveyed in Mvomero District in Morogoro Region, Tanzania.

TABLE 1 | Checklist used for the PRAs in this study.

Items	Contents
Self-introduction	Starting with investigators. Names and affiliations. Roles of officers.
Explanation about brucellosis	Causal agent, modes of infection, symptoms in humans and animals
Feedback of previous research findings on brucellosis	Prevalence and risk factors for bovine brucellosis, willingness to pay for vaccination
Customs associated with risky behaviors for brucellosis infection in humans	Drinking raw milk and cattle blood, facilitating parturition without protection against infection
Brucellosis symptoms within family	Undulant fever, headache, joint and back pain, fatigue
Explanation about brucellosis control methods, including community-based plan	Test and slaughter policy, limited diagnosis capacity in the area, mass vaccination, annual calf vaccination, and selling cows that have experienced abortion to slaughterhouse
Discussion about willingness to proceed with brucellosis control using a holistic approach	Facilitate discussions without guiding speakers

The PRAs were performed using Swahili, which is a national language in Tanzania, and English. Translation between the languages was done by Tanzanian researcher and local officers who were good at both languages. Voice recording of the PRAs was not conducted due to the communities' intentions. Thus, paper-based recording was used. **Table 1** shows the checklist prepared for the PRAs; the checklist follows the manual on participatory epidemiology (19). The research team used the checklist as the basis of the PRAs, and always started with a self-introduction. After the self-introduction by research team and the participants, the characteristics of the disease in animals and humans were explained, and the results of previous studies on brucellosis prevalence in cattle, risk factor analyses for bovine brucellosis, and willingness-to-pay for the *Brucella* vaccine were explained (9). The participants were given the opportunity to ask questions in greater depth within the disease-associated topics. After the process, participants were asked to reflect on the set of questions raised by the research team. These questions focused on risky behaviors for human infection and possible brucellosis symptoms observed in their families. Then, the research team explained general state-led brucellosis control methods (mass vaccination, test and slaughter with compensation), the option of leaving the problem, and a potential community-based brucellosis control plan that included slaughtering cows with experience of abortion and vaccinating calves, with the cost of vaccination borne by the farmers themselves (**Figure 2**). After the procedure above, participants were encouraged to discuss about favorable disease control plan, as well as methods for reducing the risk of human infection. Farmers were able to ask any technical questions and to propose any other control options. At the end of the meetings, with the facilitation and the animation by the research team and local officers, participants were encouraged to express holistic approaches to community-based brucellosis control.

The activities basically followed the order shown in **Table 1**; however, when participants mentioned a topic that was further down the list, the flow of the discussion was changed to accommodate that topic. Nonetheless, care was taken to address all of the listed topics by the end of the meetings.

In addition, key informant interviews were performed with medical officers, veterinary officers and farmers at Mvomero District Medical Office, Mvomero District Veterinary Office, village offices in Mvomero and Morogoro Urban Veterinary Office, and livestock market, respectively. The interviews were based on free discussion on any issues associated with brucellosis and its control.

RESULTS

Table 2 shows a summary of the PRAs. The numbers of farmers who participated in the PRAs were 20, 15, 30 and 20 in Mvomero, Makuyu, Milama and Wami Sokoine villages, respectively. Women participated in all of the PRAs. A medical officer participated in the PRA in Makuyu village. The participants were comprised of several tribes; no Maasai were present at the meetings held in Mvomero and Makuyu villages, but Maasai comprised the majority of participants at Milama and Wami Sokoine villages. The information obtained through the PRAs is described below.

Risky Behaviors for Human Infection

Drinking raw cattle blood is customary among the Maasai, who consume cattle blood as an alternative to food and water especially during periods of nomadic herding. The Maasai believe that raw cattle blood provides a rich source of energy and that it removes harmful elements within the body.

Drinking raw milk is conducted by all tribes because they prefer the flavor and taste of raw milk compared to boiled milk. Insofar as gender and risky behavior are concerned, assisting with the birth of calves was performed by males, and females played a dominant role in milking especially among the Maasai. Farmers treated aborted materials with their bare hands, as plastic gloves were not available in the villages. The risk of human infection by risky behaviors was not recognized by the participants and knowledge of brucellosis was poor.

Symptoms, Diagnosis and Treatment of Brucellosis in Humans

Suspected symptoms of brucellosis, such as undulant fever, headache, backache and muscular pain, were observed among the farmers and their family members. The local clinics did not have diagnostic equipment for brucellosis, and general symptomatic treatment was provided to patients who presented at clinics with brucellosis symptoms. Traditional remedies made from grasses or parts of trees were also used for treatment of febrile and pain related symptoms by households.

Selling Cattle With Experience of Abortion

Most of the adult cattle that are traded at the Mkongeni market (**Figure 1**), which was the largest livestock market in the study area, were transported to large cities such as Dar es Salaam and Morogoro Municipality for slaughter. In addition, cattle trade among cattle farmers for raising purposes was also observed in and out of the market including personal trading. In the context of disease control, it is considered preferable to slaughter cows with experience of abortion, to eliminate the source of infection for other animals. However, it is difficult for the cattle farmers to control where the cows will be sent after they have been sold at the market. In addition, the selling price would be reduced if the dealer becomes aware of any negative information about the cows being sold.

Calf Vaccinations Paid by Farmers

Since many of the farmers lacked knowledge of the *Brucella* vaccine, detailed information about the vaccine was provided to them. The cost of the vaccine was discussed frequently. Some farmers stated that vaccinating all of their calves may not be possible, especially if they have a large number of cattle; however, even in such cases, it may be possible to vaccinate selected cattle. The Makuyu community preferred to discuss the matter of the calf vaccination without the research team

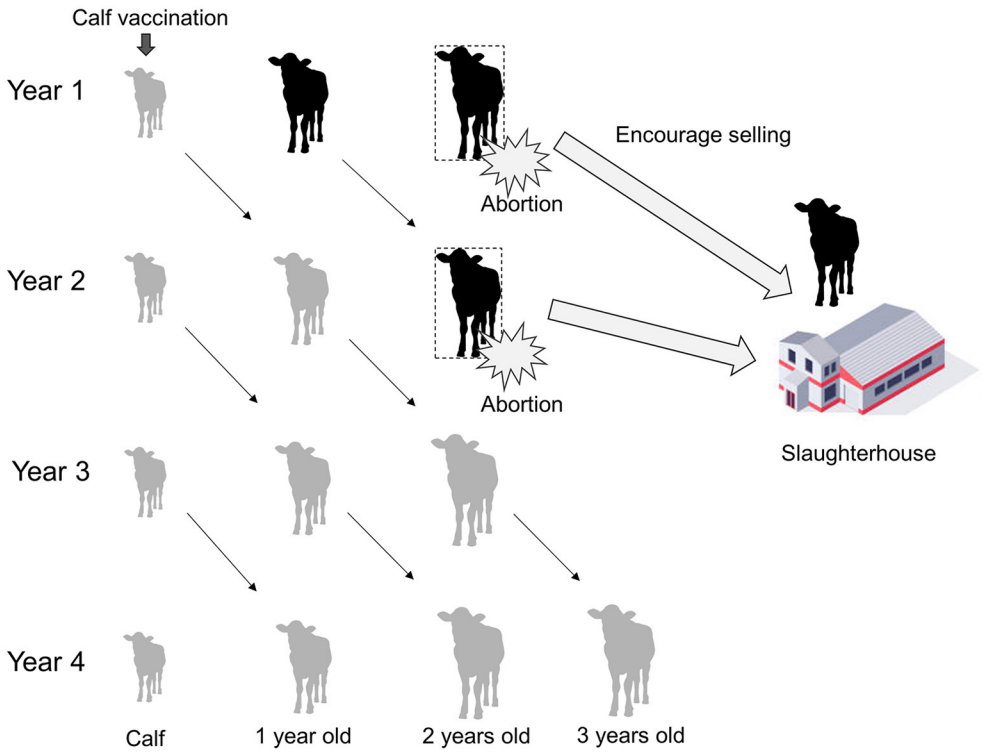

FIGURE 2 | Schematic diagram showing a community-based brucellosis control plan involving selling cows with experience of abortion for slaughter and calf vaccination paid for by the farmers themselves. By following the plan, the proportion of immunized cows increases and that of brucellosis-infected cows decreases over time.

being present, and the discussion was undertaken in that way to protect their need for privacy. Finally, all of the communities reached the same conclusion and agreed that they would bear the cost of the calf vaccinations themselves, although it may not be possible for the farmers with large herd size to vaccinate all the calves to be vaccinated. Although the vaccination strategy was briefly accepted, the chairman of the Milama village was cautious and requested inputs from the other veterinary and livestock officers who were not participating in the PRA as a supportive information for decision making. Local veterinary officers were requested to be in charge of procurement of the vaccine.

Holistic Approach Toward Brucellosis Control

In the PRAs, the rollout of the vaccination was also discussed and it was concluded that local veterinary officers were both suitably skilled and prepared to manage the process, and that they should also play a key role in the holistic community-based brucellosis control. There was a proposal to change the behaviors of children through education to prevent human infection, as changing traditional customs can be difficult for adults. Thus, from the perspective of health education, the involvement of schools and health facilities was regarded as important. In terms of how to disseminate a community-based disease control plan, the participants of the PRAs were encouraged to share the plan with their family members and other farmers.

Key Informant Interviews

Table 3 shows the key information obtained from key informant interviews. The information which were not collected from the PRAs were listed.

DISCUSSION

While this study was performed in agro-pastoral areas, our team has conducted brucellosis research since 2015 including urban areas in Morogoro Region. The research revealed that cattle raising system was different between the two areas: zero grazing, with small herd size and exotic dairy breeds in urban areas, and semi-extensive or extensive systems, with large herd size and indigenous breeds in agro-pastoral areas (8). In the comparative study, bovine brucellosis was quite limited in urban areas while prevalent in agro-pastoral areas, and higher chance of infection through grazing might be the reason for it (8). The Morogoro Municipality veterinary officers mentioned in a key informant interview that very low bovine brucellosis prevalence in urban areas was favorable, but since the disease was endemic in agro-pastoral areas and cattle from the areas were slaughtered and consumed in urban areas, the disease control in agro-pastoral areas is desirable even for urban areas (**Table 3**). Endorsed

TABLE 2 | General information about the farmers who participated in the PRA and a summary of the discussion about community-based disease control in each community.

Village (No. of farmers who participated)	Tribal composition of the participants	Summary
Mvomero ($n = 20$, male = 17, female = 3)	Several tribes and no Maasai	The community decided to proceed with the calf vaccination strategy, although the amount paid by each farmer for the vaccination differed among farmers, mainly depending on the number of cattle to be vaccinated; this was common to all of the other communities. The veterinary officers should play a major role in community-based disease control measures, especially in vaccination management; this was common to all of the other communities. Selling cows that had experienced abortion to be slaughtered is difficult due to a reduction in the selling price that occurs in response to negative information about the cattle; this was common to all of the other communities. Proposal to raise brucellosis-suspected cattle and healthy cattle separately to avoid the disease transmission.
Makuyu ($n = 15$, male = 13, female = 2)	Several tribes and no Maasai	Medical officers typically advised people to boil milk, but most of them did not. The officer commented the PRA held as part of this study may contribute to changing this behavior. Farmers discussed whether or not they could opt in of the community-based control measures by themselves, without the presence of research team.
Milama ($n = 30$, male = 28, female = 2)	Mainly Maasai	Proposal to change risky behaviors among children through education to prevent human infection was raised. The community basically agreed the community-based disease control. However, the chairman of the village also solicited opinions from other veterinary and livestock officers.
Wami Sokoine ($n = 20$, male = 17, female = 3)	Mainly Maasai	Participants expressed the opinion that all cattle farmers should participate in the community-based disease control. It was confirmed that the local veterinary officers and the farmers who participated in the PRA would share the plan with other members of the community.

TABLE 3 | Key information obtained from key informant interviews.

Interviewee	Information
Mvomero District medical officer	Maasai rarely appear to medical facilities compared to other tribes, although they tend to conduct risky behaviors of *Brucella* infection.
Mvomero local medical officer	Many of febrile cases are diagnosed as malaria or typhoid fever. There must be misdiagnosis of brucellosis cases.
Morogoro Municipality veterinary officer	Cattle from agro-pastoral areas are slaughtered and consumed in urban areas. Therefore, brucellosis control in agro-pastoral areas is desirable even for urban areas.
Mvomero local veterinary officers	Veterinary officers guide farmers to boil milk before consumption, but farmers rarely do because of their preferences of taste and flavor of raw milk and unawareness of the risk of disease infection by raw milk consumption.
Farmers at market	It is commonly recognized among farmers that cattle traded at the markets may have problems such as diseases, infertility or poor growth so that they are on the market.

by the needs from urban areas as well, our team conducted quantitative research to investigate the possibility of community-based control using cattle vaccination. High willingness-to-pay had also been confirmed by the farmers in agro-pastoral areas (9).

This PE study was undertaken to assess whether community-based disease control is feasible under circumstances in which government-led disease control is challenging due to limited resources. The PRA revealed that drinking raw milk was common among all tribes, and drinking cattle blood was conducted only by the Maasai. This qualitative information was consistent with the results of a previous quantitative study, which reported that 66.7 and 48.4% of Maasai and other tribes consumed raw milk, and 63.3 and 0.0% consumed blood, respectively (9). Focusing on Maasai, previous study revealed that they had significantly higher brucellosis prevalence than other tribes (20). However, according to Mvomero District medical officer, they rarely appear to medical facilities (**Table 3**). Considering the Maasai traditional culture, in depth information about their sociological aspects should be investigated. Regarding the raw milk consumption, veterinary officers mentioned that although they guide farmers to boil milk before consumption, they rarely change the behavior because of their preferences of taste and flavor of raw milk and unawareness of the risk of raw milk consumption (**Table 3**). In terms of gender roles and raising cattle, males assisted with parturition of cows and females performed milking. Although the magnitude of the risks posed by these activities for human infection is unclear, since no significant gender difference in terms of disease prevalence was observed in human brucellosis in the study area (male: 29.9%, female: 38.2%, Odds ratio = 0.69, 95% CI: 0.33–1.45) (20), the main route of human infection was likely related to food consumption, as reported in previous studies (20, 21).

Farmers did not have a negative opinion regarding selling cows with experience of abortion. Although abortion in cattle can be caused by a variety of reasons, since abortion is strongly associated with bovine brucellosis in endemic areas, removing cows with experience of abortion is recommended (9, 22, 23). However, from a disease mitigation standpoint, selling potentially infected cattle has both positive and negative aspects. For example, while selling infected cattle may decrease the prevalence of brucellosis on farms, unless the infected cattle go to slaughterhouses, farmer-to-farmer cattle trades for raising purposes may contribute to the spread of brucellosis to other farms. In addition, selling potentially brucellosis-infected cattle

to slaughterhouses may pose public health risks to slaughterhouse workers, meat inspectors, and consumers (7). In Tanzania, cattle that have been diagnosed with brucellosis cannot be sold for meat by law, but diagnosing all of the cattle that enter the food chain is not realistic. Thus, occupational risks for slaughterhouse workers may increase until the prevalence in animals decreases. However, as beef is typically cooked before for consumption, the public health risk posed by brucellosis from meat consumption is considered to be negligible. Further, in the absence of a national compensation scheme, selling potentially infected meat is a practical way for farmers to receive money for their animals and to mitigate brucellosis risk in cattle. Additional researches to evaluate the risks for occupation and consumption increased by proceeding selling potentially brucellosis-infected cattle and meat will determine the adequacy of the method. In addition, slaughtering high performance animals with history of abortion without brucellosis diagnosis may cause a serious issue particularly among commercial farms. Farmers mentioned their needs of diagnosis of their animals, and establishment of diagnostic service at farmers' cost should be considered.

Judging from the qualitative information obtained in the current study, the majority of cattle that are traded at the market are slaughtered rather than being sold and raised on another farm. In addition, according to the key informant interview to farmers, it is commonly recognized among farmers that cattle traded at the markets may have problems such as diseases, infertility or poor growth so that they are on the market (**Table 3**). Therefore, farmers are reluctant to buy cattle for raising purpose and this may be one of the reasons that most of the cattle traded at the market are slaughtered. In the PRAs, farmers argued that the decision of where to send the cattle that are sold at the livestock market lies with the buyers, and that disclosing that the cow had a history of abortion would decrease the selling cattle price. Although the disease-mitigation effect may outweigh the disease-spread effect, this selling policy of abortion-experienced cattle may increase inter-farm spread of the disease unless the authorities introduce some form of support.

Calf vaccination paid for by farmers themselves, which is at the center of the community-based brucellosis control plan, was accepted by all of the communities. This community-level agreement was in line with the quantitative results of a questionnaire survey which showed a high willingness among farmers to pay for calf vaccinations (9). For farmers who cannot afford to vaccinate all of their calves, we proposed that they only vaccinate new born calves as such a strategy would result in a gradual increase in vaccination coverage as the vaccination continues. This strategy would also spread the vaccination costs over time and be easier for farmers to accept. Although a rapid improvement is not expected using this calf-only vaccination strategy, slow but steady disease control, which is an important consideration in resource-limited situations, is expected over the long term. Moreover, a cost-benefit analysis of brucellosis vaccination would be helpful for decision making.

In the current study, we focused on the vaccination strategy for cattle among livestock. However, mixed livestock system especially raising sheep and/or goats along with cattle, which is very common in the study areas, was reported to be a risk factor for *Brucella* transmission between different animal species (8, 24–26). Thus, small ruminants should be included in the disease control strategy. Vaccination of sheep and goats has been successfully contributing to national brucellosis control and elimination strategies across Eastern Europe and Central Asia (27). In addition, it is reported in some countries that implementation of small ruminant vaccination reduced not only brucellosis in small ruminants and human, but also brucellosis in cattle as well, indicating that a larger proportion of bovine brucellosis is caused by *Brucella melitensis* infection than is commonly considered (27). A study conducted in Mvomero district showed the brucellosis prevalence in small ruminants was 1.4% (28), and another study reported detection of *B. abortus* from goats in Morogoro Region (29). Although the prevalence may be low, the degree to which *B. abortus* and *B. melitensis* epidemiology overlaps in mixed livestock system is unknown. Since brucellosis serological tests cannot distinguish the *Brucella* species, the isolation, identification and molecular characterization of *Brucella* spp. in the different livestock species and human are necessary to understand the transmission dynamics and to plan appropriate control measures (24). In addition, a study tried to understand cross-species *Brucerlla* transmission dynamics by integrating serological and genetic data, indicating the importance of the integration of multiple types of data (30). This kind of comprehensive study should be enhanced.

Interestingly, one of the communities discussed whether or not to participate in the community-based disease control scheme among themselves first, before informing the research team of their decision. It was considered that conducting discussions in this manner may encourage community members to speak freely and to exchange opinions honestly among themselves, leading to strong engagement and fostering a sense of responsibility for their decisions. Thus, regardless of their request, it may be better to provide participants with the opportunity to discuss such issues in meetings attended by community members only.

It was agreed in the PRAs that local veterinary officers would be in charge of vaccination management, and they would play an important role in the community-based brucellosis control. In the study areas, while working as public official, some veterinary officers have their own veterinary drug stores and sell medicines for animals, and provide veterinary medical treatment for livestock farmers. This indicates the incentives for veterinary officers in both public and private aspects in their social roles. Moreover, since farmers were not familiar with the vaccine and it was rarely used in the communities, the veterinary officer would not only be expected to manage the vaccine, but also to disseminate the correct knowledge about the vaccine and the vaccination program.

Human brucellosis is endemic to the study area where it has a prevalence of 33.3% (20). However, the diagnosis and specific treatment of human brucellosis are unfeasible in the studied communities due to the lack of materials and costs. A local medical officer mentioned that many of febrile cases were diagnosed as malaria or typhoid fever, indicating the misdiagnosis of brucellosis cases (**Table 3**). Consequently,

prevention plays an important role in tackling human brucellosis in the area. In order to improve the knowledge, awareness and practice level of people for brucellosis, any disease control program should incorporate public health education to change high-risk behaviors and prevent human infection. The Tanzanian government has recently emphasized the importance of education and the number of children who attend school in the study area is increasing (9). The World Development Report identified school health programmes as among the most cost-effective of public health interventions (31). The primary reason is that the school setting itself offers a pre-existing and comprehensive system for health delivery: there are more teachers than nurses, more schools than clinics. In addition, health-related behaviors can be modified by interventions during the school-age years. Furthermore, the aims of health education directed at children are creating awareness about the existence of diseases, giving children practical skills in how to protect themselves and the community against diseases, and encouraging children's sense of responsibility for their own health and that of their families in the future (32). Thus, while it may be difficult to change traditional customs especially among the elderly, public health education for children in collaboration with education at school, public health and animal health authorities should be effective for changing risky behaviors and its sustainability.

This study was undertaken in 2017, which is 4 years ago at the time of writing, and there could be changes in behaviors among farmers and communities due to the influence by the PRAs. Fundamentally, community-based participatory research is a co-operative and co-learning process that facilitates the reciprocal transfer of knowledge and skills between communities and researchers (33, 34). Thus, future research should evaluate the effect of the PRAs in these communities and the findings should be shared among the stakeholders, and the co-learning process should be continued.

One of the limitations of this study was that, since the research team presented the disease control plan prior to discussions among the members of the communities themselves, the participatory disease control planning may be biased by the views that were initially presented by the team. However, information including conventional state-led brucellosis control was needed to initiate an informed discussion in the groups. Participants were also encouraged to ask any technical questions and propose any ideas of community-based brucellosis control. To overcome this limitation, additional research is considered necessary to collect more information and opinions about disease control from the communities themselves and stakeholders using a variety of different participatory approaches. Moreover, participation of local administrative, veterinary, agriculture, and medical officers might cause bias in the results. Generally, in the process of designing solutions with the community, it is appropriate to suggest components of the solution. In participatory epidemiology, it is recommended to firstly ask the community for ideas on ways to control the disease and understand how far they get. Then the facilitators can suggest options and guide the community to develop an effective and acceptable program. This process is referred to as community dialogue and is an interaction between the community and facilitators as equals to develop the intervention, which should be considered in additional researches (35, 36). This study provided the first information about the view of communities, but such participatory studies should be repeated to reach saturated consensus.

The findings of this study suggested that establishing a community-based brucellosis control plan in conjunction with public and animal health authorities is feasible, which confirms the correspondence between these qualitative results and previous quantitative studies. Further, if the holistic community-based brucellosis intervention is successfully implemented, these methods could potentially be applied to other countries where brucellosis is endemic. On the other hand, even if the disease control is implemented, cases of abortion in livestock and human febrile illness will still occur due to reasons other than brucellosis (37). In addition, the long period required to observe the clear effect, due to the slow increase of the vaccination coverage by calf vaccination, may distract communities from continuation of the program. Furthermore, considering the non-specific syndromes of human brucellosis, it might be difficult for the communities to recognize clear and tangible benefits of the intervention in a short period, which indicates the risk of loss in community's interest toward disease control during the implementation of it. Thus, understanding and clear communication of the multi-factorial causes of common disease syndromes are critical to prevent loss of trust by farmers. Moreover, the intervention should be supported by periodic communications about the perceptions of impact and expectations among the stakeholders, which makes possible to manage the risk of communities' distraction. The biggest effort should be paid to quantify the economic and public health benefit of brucellosis control, and to communicate it to farmers to gain the trust first (37).

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethical Committee of the Graduate School of Dairy Science, Rakuno Gakuen University. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

SA coordinated the research, performed field surveys, and wrote the majority of the manuscript. GM contributed to field surveys. KJ and RK coordinated the research. KM designed the research and contributed to field surveys and writing the manuscript. All authors contributed to the article and approved the submitted version.

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REVIEW
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Maximising Societal Benefit From the Control of Neglected Zoonoses: Identifying Synergies and Trade-Offs in the Control of *Taenia solium*

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Interventions to control or eradicate neglected zoonoses are generally paid for through the public purse and when these interventions focus on the animal hosts, they are often expected to be performed and financed through the state veterinary service. The benefits of control, however, accrue across the human, animal, and environmental spaces and enhance both public and private interests. Additionally, disease control interventions do not take place in a vacuum and the indirect impacts of our actions should also be considered if the societal benefit of interventions is to be maximised. With the caveat that unintended consequences can and will occur, pre-identifying potential synergies and trade-offs in our disease control initiatives allows for them to be considered in intervention design and monitored during programme roll-out. In this paper, using a One Health approach with the example of *Taenia solium* control, we identify potential indirect impacts which may arise and how these may influence both our choice of intervention and opportunities to optimise the animal, environmental, and societal benefits of control through maximising synergies and minimising trade-offs.

Keywords: ***Taenia solium*, one health, control, economic analysis, societal benefit**

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INTRODUCTION

Low and middle income countries (LMICs) carry the vast majority (98%) of the health and economic burden of endemic zoonoses (1) as well as the disproportionate burden from foodborne diseases (2). Making rational decisions around the allocation of scarce resources to control these diseases is assisted by economic analysis, an approach which seeks to "add value through a search for optimality" (3). In order to undertake such analysis a problem must first be identified and described, and the potential interventions compared for their cost-effectiveness (where a non-monetary "natural" unit of health is used as the outcome) or for their benefit: cost ratio (4–6). The control of zoonotic diseases is often paid for from the public purse, reflecting the public goods occurring from these interventions, and therefore when considering the control of zoonotic pathogens, a societal perspective to economic analysis may be considered most appropriate (5). If we wish to evaluate interventions according to their overall societal impact it is necessary to first identify the synergies and trade-offs which may occur in areas outside of the primary intervention

target. Identification of these positive and negative "externalities" when designing interventions will allow for them to be monitored, potentially quantified and in the case of trade-offs, mitigate them when possible.

This paper outlines such an identification process using the example of the zoonotic parasite *Taenia solium,* the etiological agent of neurocysticercosis, one of the leading causes of acquired epilepsy in humans in endemic regions (7). This parasite is highly associated with marginalised communities where free-ranging pig production, poor sanitation coverage and lack of sufficient meat inspection converge allowing the lifecycle to propagate. The health burden, as measured by Disability Adjusted Life Years (DALYs) attributable to *T. solium* is considerable, and in the Africa-E sub-region, the sub-region in Africa with this highest childhood mortality burden (8), is estimated to be >176 DALYs/100,000 people (95% CI 134–229), making it the foodborne zoonosis with the highest health burden in this region (9).

Domestic pigs are the main intermediate host of *T. solium*, with cystercerci in the musculature (porcine cysticercosis) and consumption of raw or undercooked pork containing the cysticerci leading to the development of the adult tapeworm in the small intestine of humans (taeniosis) (10). Humans shed tapeworm eggs in faeces, contaminating the environment where these may survive for up to 9 months (11). Taeniosis in humans is typically asymptomatic, with rare sequelae including bowel obstruction and gall bladder perforation (12). Substantial health burden is caused, however through the aberrant infection of humans with the intermediate stage of the parasite after consumption of the viable eggs (human cysticercosis). In humans, the cysticerci can form in the musculature, ocular tissue and in the central nervous system causing neurocysticercosis, inducing clinical signs such as epilepsy, headaches, signs of increased intracranial pressure and focal deficits (13). The lifecycle of *T. solium* is illustrated in **Figure 1**.

There is international advocacy for intensified control strategies for the management of *T. solium,* which is a target pathogen in the 2030 World Health Organization "Road Map" for control of Neglected Tropical Diseases (14). The success of Mass Drug Administration (MDA) for major neglected tropical diseases has largely been made possible through drug donations by pharmaceutical companies (15) and the recent announcement by Bayer that Praziquantel will be made available for national *T. solium* control programmes is an exciting step (16). To date, however, control programmes for this parasite, as reviewed systematically by Coster et al. (17) have almost entirely been driven by academic research. The scale-up and sustainability of programmes going forward requires appropriate finance mechanisms, with an appropriate cost-sharing structure between the human and veterinary health sectors and between the public and private sectors, as has been recommended previously for brucellosis and rabies control (18).

To provide a rationale for investment in such control programmes based upon objective prioritisation of budgetary allocations, pragmatic and robust impact evaluations of interventions are required. To identify benefits (synergies) or potential harms (trade-offs) related to *T. solium* control, we initially consulted two systematic reviews on the subject to create a list of potential strategies (17, 19) sometimes referred to as our "toolkit of options" (20). "Health Education" was not considered as a standalone intervention within this exercise, as we consider it to be an integral aspect of all described interventions, related as it is with the promotion of specific actions within the "toolkit." With these options, which target different points in the parasitic lifecycle, in mind, we brainstormed to identify impacts of these options external to those on *T. solium* prevalence or incidence. The non-systematic approach taken to this identification process means that our framework may not be comprehensive but provides an example of the thought exercise which could be incorporated into intervention design for many pathogens.

IDENTIFYING SYNERGIES AND TRADE-OFFS FOR DIFFERENT CONTROL OPTIONS

Pharmaceutical Approaches in the Porcine Host

Highly effective pharmaceutical methods of preventing or treating *T. solium* in the porcine host have been developed. Oxfendazole (OFZ) at a single oral dose of 30 mg/kg has been recognised as being highly effective to treat the infection (21, 22) and is the drug of choice due to lack of negative effects, minimal cost and relatively short withdrawal periods (8–14 days). A porcine formulation of OFZ (Paranthic® 10%) is now manufactured but only licenced for use in some African countries (23). Use of OFZ will not prevent reintroduction of the parasite, however. The vaccine TSOL18 has proved highly effective at preventing porcine infections, or preventing re-infection after OFZ treatment in several field trials (24–26). This vaccine is now under commercial production as Cysvax® and has been licensed in several countries (27).

There is currently no evidence that porcine cysticercosis (PCC) in itself causes any visible reduction in productivity, and in countries where few disincentives exist for presenting infected pigs to slaughter, the willingness of farmers to pay for a vaccine appears to be low (28). With the balance of benefits from vaccination heavily tipped toward the public health sector, there would be a strong argument for public health provision or subsidisation of rolling out the vaccine. Opportunities exist however, to "bundle" the TSOL18 vaccine with others for production limiting diseases similar to a trial undertaken in Laos where the TSOL18 vaccine was rolled out alongside vaccination for classical swine fever (CSF) (29). Partial budget analysis of this intervention indicated a positive benefit: cost ratio to farmers, driven by the mitigation of production losses due to CSF (29).

In contrast OFZ has intrinsic private benefit to pig farmers through the synergistic impact on other endoparasites which have a negative effect on productivity, in particular the main nematodes occurring in pigs (*Ascaris suum*, *Strongyles* spp, *Oesophagostomum* spp, and *Trichuris suis*) (22, 30). Many studies of gastro-intestinal parasites of pigs raised under low-input systems in the countries in which *T. solium* is endemic have demonstrated a high prevalence of these infections (31–35),

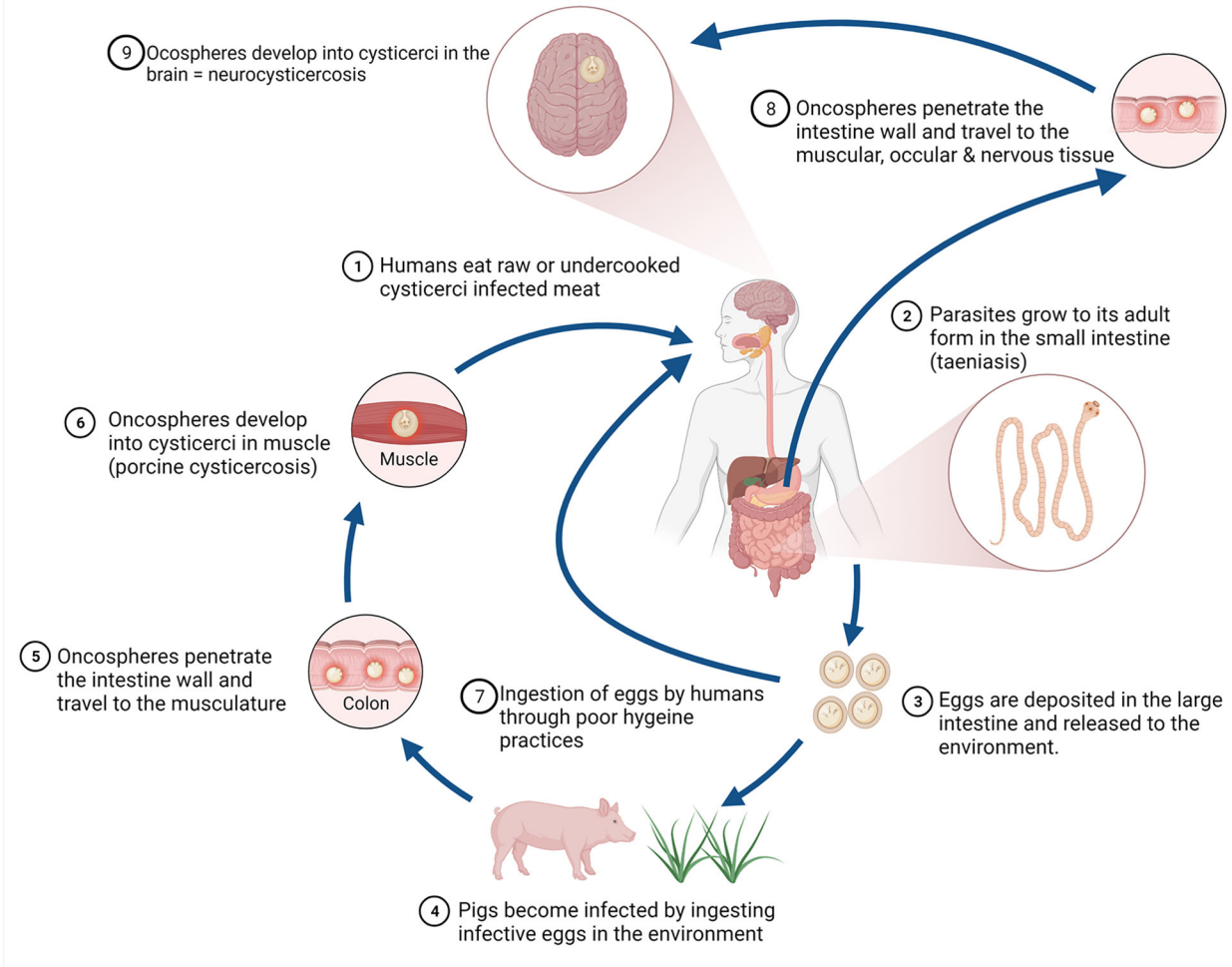

FIGURE 1 | Life cycle of *Taenia solium*. Figure created with BioRender.com.

which will impact on feed conversion efficiency and kill-out percentage, translating into a real constraint on their pork production enterprises (36). Demonstrating to farmers the financial benefits of adopting OFZ treatment in their pigs has the potential to improve the willingness to pay (WTP) for this control option.

The use of anthelmintic treatments does however come with potential negative consequences, in this case the potential human health impacts due to the presence of residues in meat, development of anthelmintic resistance and ecotoxicity from residues accumulating in the environment.

Concerns over potential toxicity or hypersensitivity in humans consuming meat containing drug residues led to the setting of maximum residue limits (MRL) for drugs licensed for veterinary use. The pharmacokinetics of different drugs informs the time which must elapse (withdrawal time) before meat from treated animals is fit for human consumption. The benzimidazole family of which OFZ is a member appear to be stable in meat even after cooking (37), so residues present at slaughter are highly likely to be ingested at consumption. Poor enforcement of residue limits within the resource-constrained settings in which *T. solium* is endemic, leave open the potential that meat may be consumed with residues over the MRL (38).

As the benzimidazole class is widely used in veterinary and human medicine, the development of anthelminthic resistance to OFZ must also be considered as a potential negative consequence of intensified use for *T. solium* control (39). The extensive systems in which many pigs are raised in endemic areas may slow the selection pressure in the parasite, but consideration should be made of this potential when intervention programmes are developed to avoid the resistance issues already faced by the ruminant livestock sector (40, 41).

Ecotoxicity from compounds of the benzimidazoles has been demonstrated in aquatic and terrestrial organisms (42, 43). Drugs from this class have been demonstrated to be excreted in faeces and urine predominately in an unaltered, active state, and that these compounds can persist in porcine faecal material for periods of a hundred days or more after excretion (44). Consideration of the ecosystem services of organisms impacted by anthelmintic residues is an important aspect of any impact

evaluation from a truly societal perspective, and risk mitigation measures should be considered to protect the environment, with particular care being taken to avoid water contamination from the dung of treated animals (45).

Porcine Husbandry Interventions

The OIE Terrestrial Animal Health Code for the control of PCC does not consider pharmaceutical treatments, and instead focuses on farm husbandry approaches which prevent the direct and indirect exposure of pigs to untreated human faeces (46). There is an evident correlation between husbandry practices and the risk of PCC, with studies demonstrating a significantly higher sero-prevalence in extensively kept pigs compared to those raised in more intensive conditions due to increased transmission opportunities from environments contaminated by eggs (47–49).

Confinement of pigs to restrict their access to contaminated soil and water reduces the risk of acquiring PCC as well as other pathogens of public health and production importance. The improved biosecurity resulting from pig confinement reduces the potential for transmission of African swine fever (ASF), a virulent viral infection with high levels of mortality amongst infected pigs which can be spread by direct contact with an infected pig or warthog, through the bite of an infected tick or via contact with fomites carrying the virus (50, 51). ASF is an important production-limiting disease across sub-Saharan Africa where *T. solium* is endemic and risk reduction for ASF may be an incentive to farmers to adopt improved practices. Confinement of animals and the provision of supplementary feed also provides an opportunity to improve average daily weight gain, thereby shortening the time taken to raise a pig to slaughter weight which may result in improved gross margin for the pig production enterprise.

The profitability of small-holder pig farming enterprises, however, is often based upon narrow margins and demonstrates a significant influence from the cost of feeds, with a study in Kenya indicating that a 1% increase in feed costs had the potential to reduce pig enterprise profitability by 25% (52). This demonstrates a potential risk to farmer livelihoods when previously low-input enterprises are moved into a confined system which becomes highly reliant on this one key input. Further research is needed on farm enterprise economics to provide data to farmers on the potential monetary return on investment from enhanced husbandry practices including confinement, appropriate feeding, and biosecurity.

Making changes in a livestock enterprise which require additional labour inputs, for the collection of feeds, cleaning of pens etc, can also alter the inter-household gender distribution of labour. There are examples of these additional tasks falling predominately onto the women in the family, particularly where small-stock are concerned (53), potentially reducing the time available for other opportunities inside or outside the household (54). If the finances generated by a livestock enterprise remain in the control of a female household head there is evidence that this may increase the nutritional outcomes of the children in that household (55). Despite a reliance on female labour to care for confined pigs, as a livestock enterprise commercialises, the control of the enterprise may pass to the male head of the household. In these cases, the women not only lose control of the money generated by the enterprise but may not have sufficient agency in the household to request for veterinary inputs, or make other important management decisions (56), reducing effective livestock management based on daily observations of the animals. Understanding the intra-household gender dynamics and ensuring that changes in the livestock enterprise are made in a way which acknowledges and preferably seeks to transform these dynamics is paramount.

Trade-offs in shifting small-holder pig production from a free-ranging to a confined production model also include potential detriments to animal health and welfare and environmental concerns. Carriage and shedding of key microbial pathogens, such as *Salmonella* and *Campylobacter* spp., can be exacerbated under confined conditions, in turn increasing the risk to consumers of acquiring these foodborne diseases and requiring close monitoring for the protection of public health (57, 58).

Careful attention must also be given to the appropriateness of pig housing to avoid animal welfare and health problems. Although consideration of animal welfare is a relatively new area of concern within many endemic countries, there is evidence of consumers' increasing interest in the topic and a willingness-to-pay for improved welfare in livestock production systems has been documented in Kenya, indicating an economic driver for ensuring high welfare standards (59, 60). There is also an argument that economic evaluations from a societal perspective should explicitly consider and value animal welfare as a social welfare function (61). The OIE terrestrial code establishes animal welfare specific recommendations for pig keeping which can be adapted to the endemic settings (62).

The location of confined pig production in relation to its impact on land-use changes, and proximity to habitat for high-potential zoonotic disease hosts such as bats and rats is an important consideration, as demonstrated by the concurrent intensification of mango and pig farming in the Malaysian peninsula in the late 1990's which resulted in the spillover of Nipah virus into humans (63). Human-to-human transmission of the virus, which causes neurological symptoms and has a high fatality rate, has now been identified in Bangladesh, subsequent to multiple independent spillover events driven by land-use change (64).

Environmental externalities may also arise from confinement of livestock, including the land and water footprint of growing additional crops for pig feed and the potential leachate from pesticide, herbicide and fertiliser used on these crops. The environmental impact of pig manure will depend upon the production system adopted and the manure management strategies applied. Water contamination with faecal material introduces pathogens and antimicrobial resistant bacteria/pathogens into the environment which may be transmitted to other animals or man. Drug residues have the potential to be toxic to the aquatic ecosystem whilst nitrates in manure lead to eutrophication and the death of aquatic organisms and those which rely on them (65). Pig manure releases the greenhouse gases (GHG) nitrous oxide (N_2O), methane (CH_4) and carbon dioxide (CO_2) and also causes a public nuisance from odour (66). The increased density of pigs kept under a confined system,

particularly when combined with industrial agglomeration can lead to high environmental impacts in these areas. The spatial aggregation of pork production in high income countries has been demonstrated to improve the profitability of individual farms, and it could be expected that as the pig industries in LMICs intensify, similar agglomerations will occur as farms cluster around the source of feed provision or in localities with strong market demand.

Appropriate waste management strategies will be required to mitigate these impacts if farmers are to be encouraged to move toward intensified systems which in turn is likely to necessitate a strong regulatory framework. Best practice manure management may not only mitigate the negative environmental externalities of changes in husbandry practices, but may also result in private sector benefits where appropriately treated manure is spread in appropriate quantities on crop land, or utilised for renewable electricity production if capital is available (67).

Interventions Relating to Food Safety Legislation

The key legislative requirements relevant to the control of *T. solium* are the regulations relating to the inspection of meat products. Ante- and post-mortem inspections conducted at abattoirs aim to protect both animal and human health by preventing, detecting and controlling hazards originating from animals (68). This process provides one of the key synergies between control of zoonoses and improvements in food safety. Along with *Taenia solium* (69) several zoonotic diseases present within sub-Saharan Africa may have either clinical signs or detectable lesions at inspection including tuberculosis (*Mycobacterium bovis*) and *Ascaris suum* infection (70–72).

Meat inspection also serves as an important source of surveillance and a detection point for contagious and production animal diseases, allowing appropriate, timely control activities to be conducted. These diseases include African swine fever, classical swine fever, and foot-and-mouth disease (71). The early detection and control of contagious disease is especially important for small-holders, in order to protect farmer livelihoods and financial security within vulnerable communities (73). The meat from pigs slaughtered at a registered abattoir complying with the relevant legislation and meat inspection, are usually subject to more hygienic slaughter practices and are at a lower risk of foodborne bacterial contamination (74). Additionally, the diagnosis of pathological and welfare conditions by trained personnel during abattoir inspection can serve as an important source of information to the farmer in order to improve animal health, production and welfare (75). Aiming for health maximisation through the rectification of disease conditions can lead to an increase in herd well-being and productivity and to a decrease in losses incurred by the farmer (76).

"Traditional" meat inspection, reliant on visualisation, palpation and incisions and as practised in the majority of *T. solium* endemic countries is, however, relatively insensitive in detecting cysticerci (77) and has no efficacy in relation to microbial hazards (78). The process of palpation and incisions can be time-consuming for the inspector whilst acting as a source of cross-contamination of the carcass by microbial pathogens (78, 79). Freezing of infected carcasses at −20°C for 1–3 days has been demonstrated to be successful in killing cysticerci (80). However, in many of the regions where the parasite is endemic, the infrastructure for this may not be readily available, while the process can also reduce the value of the carcass, and may render the meat unacceptable to consumers who prefer fresh meat (81). The enforcement of meat inspection regulations and subsequent condemnation or downgrading of meat can drive infected meat into the informal "black" market, exacerbated by the poor enforcement of legislation, inadequate numbers of veterinary public health officials, and periods where the demand for meat is high (82). Pigs may be lingually examined for *T. solium* cysts by traders prior to purchase and slaughter, and positive animals illegally slaughtered or sold at a lower price (83, 84). These informal markets have the potential to reduce the financial risk to farmers and traders, as they provide a conduit for selling meat which would otherwise be condemned, but they directly reinforce inequity in access to food safety where the poorest consumers continue to be exposed to food safety hazards which richer consumers are protected from (74). The education of consumers is essential, as these practices are unlikely to be contained if the high demand for illegally slaughtered meat persists (82).

Pharmaceutical Interventions in the Human Host

The use of mass drug administration (MDA) in human populations at risk of infection is a mainstay of control programmes for neglected tropical diseases, including soil transmitted helminths (STH), schistosomiasis, lymphatic filariasis, onchocerciasis and trachoma, and over a billion people a year are currently treated across Asia, Africa and Latin America. These programmes have demonstrated dramatic reduction in disease burden, both for their intended targets and for many additional diseases which were unexpected targets at programme inception (85). The integration of vertical, single disease focused interventions into interventions for multiple diseases, or within wider health system services will provide opportunities for improved economies of scale and scope (86).

Praziquantel at 40 mg/kg is effective against both *T. solium* and schistosomiasis (87), whilst a triple dose of 400 mg albendazole is effective against *T. solium* and STH (88). Understanding co-endemicity of these parasites is therefore important to guide the best choice of pharmaceutical agent in order to enhance the synergies of MDA programmes. These synergies can be captured quantitatively through consideration of the DALYs averted through MDA. In Laos PDR the cost-effectiveness of the MDA component of a combined human-pig intervention was strongly driven by the treatment of STH which was causing widespread morbidity in the community (29). Many additional benefits have been indicated to accrue from the mass treatment of gastro-intestinal parasites including; improved weight gain, improved school assessment scores and

even improved labour market outcomes later in life as reviewed in 2017 by Ahuja et al. (89).

Potential negative externalities of widespread anthelmintic use in human populations include social mistrust, eco-toxicity, anthelmintic resistance, and potential adverse reactions. Praziquantel crosses the blood-brain barrier, and the potential for its use to trigger epilepsy in latent neurocysticercosis sufferers is being closely monitored by those conducting MDA programmes (90). Anthelmintic resistance has not yet been reported in the large MDA programmes already running for schistosomiasis and STH, but monitoring should nonetheless continue (91). Ecotoxicity has been discussed under porcine pharmaceutical interventions but is an under-studied area within the context of MDA for NTDs. The ethics of MDA have been questioned on occasion and the potential to cause social unrest and mistrust of the health care system has been documented (92) and some of the stated benefits of school-based programmes are under debate, with more evidence required to monitor and quantify them (93).

Water, Sanitation, and Hygiene (WASH) Related Interventions

Other potential interventions for *T. solium* targeted at the human host include the provision of improved sanitation infrastructure and of appropriate and context-specific health education messages related to sanitation, personal hygiene, and safe food preparation. In vulnerable communities of sub-Saharan Africa, although sanitation has improved over the last two decades, hand washing facilities are absent or deficient in 75% of households, 39% don't have access to safely managed drinking water and open defecation is still practised in ∼70% of the population (94). Open defecation results in propagation of the tapeworm cycle whilst inadequate hand washing facilities and unsafe drinking water are contributing factors to human cysticercosis (95).

Improving societal sanitation and hygiene through increased latrine and potable water coverage and education on safe food preparation potentially has the opportunity for the greatest added value amongst any of the interventions discussed, due to the protective effect on many other pathogens, including diarrheal agents. Diarrheal diseases are responsible for one of the highest burdens of disease across LMICs, accounting for 1 in 9 child deaths worldwide, with more children dying on a daily basis from diarrheal pathogens than from AIDs, malaria and measles combined (96). Whilst rotavirus vaccination and improvements in breastfeeding rates have been responsible for some of the decrease in burden from diarrheal diseases in the last 20 years (97), there is a consensus that WASH programmes including the adoption of systems for treating and storing drinking water, health education and latrine provision have made cost-effective contributions to this decline (98). The United Nations have recognised that clean water and sanitation are a basic human right, and the public health protection endowed by WASH services, enables a productive and prosperous society, indicating that the strong correlation between Human Development Index and WASH service provision may be self-reinforcing rather than a uni-directional relationship (99).

Despite the potential for different WASH interventions to disrupt *T. solium* transmission, only two control trials to date have attempted to monitor the impact specifically on this parasite (100, 101). In Burkina Faso the intervention appeared effective in reducing active human cysticercosis prevalence in one of the two study districts, demonstrating the potential for WASH interventions to be part of intensified control of *T. solium*. In Zambia, the programme failed to achieve sufficient latrine usage within the target community for a variety of reasons including cultural taboos related to who can have latrine access, and the intervention failed to make an impact on the prevalence of *T. solium* (101, 102). Yet the strong rationale for increasing basic sanitation levels as an integral aspect of sustainable development is undeniable.

Careful planning is required in order to minimise any potential negative externalities of such programme in terms of environmental contamination, odour, or public nuisance. Accounting for socio-cultural taboos regarding sharing of latrine facilities (102), and the need to ensure safety of facilities is also important to ensure equity in access across age and gender groups (103). If appropriate sewage treatment facilities are not available or suitable for the context, night-soil may be collected for use of fertiliser. Although this product offers large soil fertility benefits, the presence of potentially pathogenic microbes including viable *T. solium* eggs in this night-soil, requires that the product is carefully stored and treated prior to utilising it on pasture-land or plantations where pigs could acquire access (104).

A ONE HEALTH FRAMEWORK TO IDENTIFY, MONITOR, AND QUANTIFY THE SYNERGIES AND TRADE-OFFS OF ZOONOTIC DISEASE CONTROL

As a trans-disciplinary framework for solving complex problems across the human, animal, and environmental interface, we consider that the logical conclusion of a One Health approach is the evaluation of interventions from a societal perspective, aiming to maximise net societal benefit. As described here through the example of *T. solium* control, disease control interventions may provide both positive and negative externalities, "synergies and trade-offs" to a range of stakeholders. It is only through identifying these potential synergies as well as the negative impacts which may occur that the appropriate baseline and post-intervention monitoring can occur. **Table 1** summarises the externalities we have described in this manuscript and indicates potential areas to monitor or mitigate. We have drawn these examples from our own brainstorming sessions and therefore cannot state that we have comprehensively identified all potential externalities.

The most appropriate intervention for any one pathogen will be context specific. The contextual factors for consideration within *T. solium* control have been summarised by Ngwili et al. (105), and include the epidemiological, socio-economic, cultural, historic, geographical and climatic context as well as considering aspects of institutional capacity including the

TABLE 1 | Summary of control strategies with potential synergies and trade-offs.

Strategy	Potential synergies	Potential trade offs	Activities to enhance synergies & mitigate trade-offs
Porcine anthelmintic ± vaccine	Reduced GI parasite burden, improve weight gain & farm profitability **Monitor:** Faecal egg counts, daily weight gain & farm enterprise profitability	Anthelmintic resistance, hypersensitivity reactions in humans, ecotoxicity to aquatic or terrestrial spp. **Monitor:** Monitor resistance levels, residues in meat, ecological monitoring of appropriate indicator species	Provide appropriate extension services to enhance husbandry & health care practices including rational anthelmintic use Bundle TSOL18 vaccine with context appropriate vaccines for production limiting diseases Disseminate farm enterprise profitability data to stimulate investment and identify "champion" farmers as advocates Enhance meat inspection to incentivize production of "clean pigs" and instigate residue testing
Confinement of pigs with appropriate supplementary feeding	Reduced disease transmission from roaming pigs, improved weight gains & farm enterprise profitability **Monitor**; Incidence of clinical episodes, daily weight gain & farm enterprise profitability	Animal welfare breaches from inappropriate housing, tight tethers, insufficient feed & water provision, disease transmission from overstocking/poor ventilation. **Monitor**; On farm or at slaughter welfare assessments including lung scoring at slaughter. On farm incidence of disease Environmental contamination from manure. **Monitor**; Manure management practices, GHG emission intensity and water contamination Increased reliance on women's labour without commensurate benefits to women. **Monitor**; inter-household labour and resource allocation	Provide appropriate extension services to enhance husbandry & health care practices including education on locally available feeds and ration formulation, pen construction and manure management practices Improve access to animal health provision Disseminate farm enterprise profitability data to stimulate investment and identify 'champion' farmers as advocates Incorporate gender transformative approaches in intervention design
Meat inspection	Improved control of zoonoses, foodborne disease and transboundary animal diseases. **Monitor**; Reports and condemnations from meat inspectors	Economic shock to resource poor farmers or traders on condemnation of meat. **Monitor**; Number of condemnations, Stimulate an informal 'black' market for sub-optimal meat **Monitor**; covert operations by law-enforcement to identify extent of black market Threat of retaliation for meat inspector. **Monitor**; perception of inspector of their ability to perform their jobs Bacterial cross-contamination from incisions. **Monitor**; Monitor microbial contamination of meat.	Provide farmers with the tools and agency to raise 'clean' pigs Educate consumers to demand inspected meat (knowledge of health mark stamps etc) Investment to ensure full complement of staff, with regular training and provision of mobile phone reporting tools and facilitate use Empower meat inspectors to condemn unfit meat and provide law enforcement backing Monitor relative burden of parasitic vs microbial FBD and develop traceability options to enable risk-based approaches to inspection
Human anthelmintic treatment	Reduced burden of schistosomiasis and soil transmitted helminths leading to improved health and educational outcomes. **Monitor**; Prevalence of other parasitic infections, school attendance and attainment	Latent NCC may be stimulated **Monitor**; closely for adverse drug reactions Anthelmintic resistance **Monitor**; resistance profiles of targeted parasites Terrestrial and aquatic ecotoxicity **Monitor**; population of key indicator species Community unrest and resistance to programmes. **Monitor**; refusals to participate in programmes	Plan treatment programmes using co-endemicity maps to ensure most appropriate treatment regime. Undertake screening for potential NCC and adjust PRZ dose appropriately and Use Mass Drug Administration programmes only where necessary. Enhance latrine provision to reduce environmental contamination. Ensure a careful, culturally appropriate sensitisation programme with regular community consultation
Water, sanitation, and hygiene interventions	Reduced burden of diarrheal diseases. **Monitor**; incidence and burden of diarrheal disease Utilisation of night soil for fertiliser or biogas generation **Monitor**; number of households with composting latrines or biogas generation	Fear of breaking taboos, violence or injury **Monitor**; latrine use as well as coverage Use of night-soil as fertiliser may spread pathogens **Monitor**; treatment time and temperature and viability of pathogens before use on crops	Initiate with appropriate anthropological engagement with community to ensure latrine construction adheres to local cultural context and that access to latrines is safe and equitable Provide a strong sensitisation programme on benefits of WASH programmes. Utilise Community led total sanitation to enhance community uptake Provide extension services to promote alternative night-soil uses and ensure night-soil is fully treated to kill pathogens before use as fertiliser

presence of appropriate legislature, resource and political will. When considering the epidemiological context, the identification of additional "secondary" disease targets highlights the need to appropriately understand the co-endemnicity of different pathogens. In the case of *T. solium* for example, a high degree of co-endemicity of schistosomiasis or STH may favour a MDA

approach in the human host, while the presence of production-limiting diseases of pigs may favour the potential to bundle a contextually relevant porcine vaccine alongside Cysvac®, such as the combination with classical swine fever vaccine in Lao PDR (29). Where the burden of *T. solium* is high, enhanced meat inspection techniques with targeted palpation and incisions may be the most appropriate method to support ongoing control. When the balance of burden shifts so that microbial hazards such as *Salmonella* spp., *Campylobacter* spp. and *Yersinia entrocolitica* become dominant, a risk-based approach with reduced incisions and opportunities for cross-contamination, may become most appropriate, requiring the presence of robust traceability systems (106).

In the majority of *T. solium* endemic communities pig production systems are poorly developed with consequent low productivity (107), whilst open defecation is practised by communities due to low or inappropriate latrine provision (102, 108). Given the potential to mechanically disrupt parasite transmission and the potential for high-value synergies with other human health, food security and economic development programmes by addressing these issues, we strongly recommend a heightened focus on these areas whilst ensuring that mitigation measures for potential trade-offs are designed in at conception.

Designing appropriate extension packages to promote best practice in animal health, feeding, environmental management, whilst optimising the gender equity, and animal welfare is a complex task and promoting adoption even harder. A thorough understanding of people's motivations for engaging with pig production, their financial and societal constraints and aspirations is needed. Incentives for engagement may be financial, requiring evaluation and dissemination of farm enterprise budget data or may be through increased social capital, due to societal recognition of good, "clean" pig production. Identification of local "champion" farmers, those managing their pigs under sanitary conditions whilst enhancing animal welfare and environmental protection through use of best practices, would provide an opportunity to promote such practices to other pig farmers within a similar context.

Legislation may also play a role in motivating farmers to improve production, for example enhancement of meat inspection services and the risk of condemnation of pigs may stimulate the uptake of pharmaceutical interventions (109). Understanding the way in which the pork value chain operates, the degree of integration and the governance structures can allow for interventions to be embedded in a systems approach and allow evaluation across different actors. Ex-ante modelling of ASF control options which incorporated enhanced biosecurity alongside the development of an integrated business model where farmers were integrated into a co-operative with which dedicated traders interact. Whilst implementation of biosecurity by farmers reduced ASF outbreaks, the profitability of the pig enterprise was projected to be compromised by the intervention, whereas the combination of a market-based intervention alongside improved biosecurity improved the profitability of all actors in the value chain, whilst stabilising the supply and price of pork to the consumer, demonstrating the utility of such a systems-based approach (110).

Evaluating interventions which create impacts across multiple dimensions is challenging. Economic evaluation approaches which can be used both *ex-ante* and *ex-post,* such as cost-benefit analysis (CBA) or cost-effectiveness analysis (CEA) require standardisation of costs and benefits, either into monetary terms (CBA) or by quantifying outcomes in appropriate non-monetary units (CEA). Within health care CEA using a non-monetary health metric combining mortality and morbidity such as the Quality Adjusted Life Year (QALY) or Disability Adjusted Life Year (DALY) is a mainstream approach and is mandated in several countries to provide justification for public investment in health technologies. Two approaches have been suggested to combine human and animal health outcomes, either into monetary terms for CBA or into a combined metric for CEA—the zoonoses-DALY (111, 112). It would appear that neither approach precludes combining additional impacts such as changes in ecosystem services, though the complexity, and difficulty in providing quantitative estimates of impacts may preclude their use. An alternative approach for decision making, often used to aid complex investment decisions is multi-criteria decision analysis (MCDA). Various MCDA are available which can include qualitative as well as quantitative data and their use is increasing in the realm of health policy (113). MCDA has been used to assist stakeholders in evaluating options for Lyme disease control, using an semi-quantitative assessment of impact across five critical domains, being; Public Health, Animal & Environmental Health, Social Impact, Strategic & Operational criteria and surveillance criteria (113). The MCDA provided a transparent process for decision making in which the weighting of criteria by stakeholders provides an explicit expression of the values stakeholder's place upon different impact domains.

We acknowledge that whilst designing interventions we may never fully anticipate all unintended consequences and attempting to do so may result in paralysis. We do consider, however, that whilst there is a need to provide "boundaries" to our problems, identifying positive, and negative externalities of our actions provides us a framework within which a broader societal perspective can be taken in our design and evaluation of interventions. We recommend further consideration of expanded economic evaluation frameworks suitable for tackling problems at the animal, human, environmental interface, or the further adoption of multi-criteria decision analysis in the field of zoonoses control. In this paper we have described many broader impacts relating to *T. solium* control and we hope this stimulates consideration by those designing control trials to expand intervention monitoring across these different domains.

CONCLUSION

In conclusion, appropriate monitoring of intervention impacts is difficult and time consuming, particularly when these impacts fall across different sectors. We recommend programmes

start by identifying key potential synergies and trade-offs so that they can be supported to look outside the primary target of a campaign into areas where societal benefit can truly be maximised and, where possible, quantified. We also recommend the development of appropriate One Health economic evaluation frameworks, integrating animal and human health, environmental economics and multi-criteria analysis to aid decision making and guide appropriate resource allocation to zoonotic disease control interventions.

AUTHOR CONTRIBUTIONS

LT: conception. CS, AG-A, AS, MU, and LT: first draft. All authors read and approved the final draft of the manuscript.

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Prevalence, Antibiogram, and Multidrug-Resistant Profile of *E. coli* O157: H7 in Retail Raw Beef in Addis Ababa, Ethiopia

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Escherichia coli O157:H7 is an emerging foodborne pathogen of public health importance. The objectives of this study were to estimate the prevalence and evaluate the antimicrobial susceptibility pattern and multidrug-resistant profile of *E. coli* O157:H7 isolated from raw beef sold in butcher shops in Addis Ababa, Ethiopia. A total of 384 raw beef samples were collected from randomly selected butcher shops across the 10 sub-cities of Addis Ababa. *E. coli* O157:H7 was isolated following ISO-16654:2001 standard, and isolates were tested for resistance to 13 antimicrobial agents using the Kirby–Bauer disk diffusion method. Out of the 384 retail raw beef samples examined, 14 (3.64%) (95% CI = 1.77–5.51%) carried *E. coli* O157:H7 serotype. Of the 14 *E. coli* O157:H7 isolates, 8 (57.14%) were found to be resistant to three or more antimicrobial categories. The frequency of resistant phenotype was more common for ampicillin (92.8%), nitrofurantoin (92.8%), and tetracycline (50%). Multidrug-resistant *E. coli* O157:H7 were present in raw beef sold in butcher shops in Addis Ababa. Thus, more stringent monitoring of antimicrobial use in both human and animal populations should be implemented. In addition, further studies should be conducted to understand the *E. coli* O157:H7 points of contamination and define appropriate risk mitigation strategies.

Keywords: Addis Ababa, antimicrobial, beef, *Escherichia coli* O157:H7, prevalence

INTRODUCTION

Escherichia coli O157:H7 is an emerging bacterial zoonotic foodborne pathogen of global significance for which cattle is the primary reservoir (1). Cattle shed the bacteria into the environment in their faces, which are then transmitted to humans primarily through the consumption of contaminated raw or undercooked meat (2, 3). The contamination of cattle carcasses or beef can occur during processing and manipulation, such as skinning, evisceration in slaughterhouse, and distribution to butcher shops (4).

While cattle that carry *E. coli* O157:H7 are asymptomatic, infected humans show clinical manifestations ranging from asymptomatic (carrier state) to serious illness. The bacteria adhere to

the gut wall of infected people and cause hemorrhagic colitis. Besides, the pathogen also produces toxins that can cause life-threatening complications including hemolytic uremic syndrome (HUS) and thrombotic thrombocytopenic purpura (5, 6).

Early antimicrobial treatment can prevent Shiga toxin-producing *E. coli* O157:H7 infection progression to the HUS (7–9). Studies have shown a significant increase in antimicrobial resistance in *E. coli* O157:H7 (8). This in part may be related to the overuse and misuse of antibiotics in people and food animals (10). In Ethiopia, studies have been confirmed that *E. coli* O157:H7 have developed different percentages of resistance against various commonly used antimicrobial drugs including ampicillin, cephalothin, streptomycin, tetracycline, trimethoprim, amikacin, amoxicillin-clavulanic acid, ciprofloxacin, nalidixic acid, streptomycin, chloramphenicol, nitrofurantoin, and erythromycin (11–18).

Ethiopian food culture includes eating raw beef "Kurt" or minced raw beef "Kitfo," which increases people's exposure to pathogens. Despite the risk of exposure to *E. coli* O157:H7, limited studies on the magnitude of contamination and risk of *E. coli* O157:H7 and antimicrobial susceptibility has been reported, particularly from developing countries including Ethiopia (19). Such studies can provide valuable information to help in the implementation of strategies to minimize contamination levels.

Earlier studies have reported the occurrence of *E. coli* O157:H7 on raw beef from butcher shops in Ethiopia with results in the range of 0.8–21.9% (11, 12, 14–16). However, the previous studies tend to suffer from small samples and sampling approaches that fail to obtain a representative sample of a population of interest.

Therefore, this study was designed to estimate the prevalence and evaluate the antimicrobial susceptibility pattern and multidrug-resistant profile of *E. coli* O157:H7 isolated from raw beef sold in butcher shops in Addis Ababa, Ethiopia.

MATERIALS AND METHODS

Study Area

The study was carried out in Addis Ababa, the capital city of Ethiopia. The city covers 540 km^2 and is divided into 10 sub-cities (**Figure 1**). The city lies at an elevation of 2,355 m above sea level and is located at 9°1′48″N 38°44′24″E. The city has minimum, maximum, and average temperatures of 14, 21 and 17.5°C, respectively. The capital city has an estimated human population of 3.15 million.

Study Design and Sample Size Determination

A cross-sectional study was conducted from October 2018 to December 2019 to determine the prevalence and antimicrobial susceptibility pattern and multidrug-resistant profile of *E. coli* O157:H7 serotypes in retail raw beef samples obtained from butchery shops, in Addis Ababa, the capital city of Ethiopia.

The sample size required was calculated according to Thrusfield (21), from an expected pooled prevalence of 6.5 for the butcher shops (11, 12, 14–16) with a defined precision of 5% and a level of confidence of 95%.

$$n = Z^2 P_{exp}(1 - P_e xp)/d^2 \quad (1)$$

where Z = z statistic for level of confidence; n = required sample size; P_{exp} = expected prevalence and a desired absolute precision (d) of 0.05, Z = 1.96. Therefore, the minimum sample sizes were 49 butcher shops. However, in order to increase the precision of the study, a total of 384 butcher shops were included.

Study Samples and Sampling Methods

The study samples were retail raw beef. A list of active and legally registered butcher shops within the 10 sub-cites and their distribution lines were obtained from Addis Ababa Abattoir Enterprise. A total of 384 butcher shops were selected using the simple random sampling method, and the butcher shops were visited only once A raw beef sample was purchased from each of the randomly selected butcher shops as it was sold to the consumer.

Each sample was placed in a sterile individual plastic bag. The sample was identified by its exclusive sample identification number, which was written on the plastic bag, alongside the sub-city and the date of sampling. Finally, the sample was transported to the Microbiology Laboratory of the Aklilu Lemma Institute of Pathobiology, Addis Ababa University, at cold temperature in a cool box. Upon arrival to the laboratory, the samples were stored in a refrigerator at ±4°C. The samples were processed within 6–12 h from arrival. The detection of *E. coli* O157:H7 was administered consistent with the protocol of ISO-16654:2001 standard (11).

Sample Preparation and Enrichment

Twenty-five grams of raw beef was weighed and cut into smaller pieces with a sterile scalpel blade on a sterile plate and put in a sterile Stomacher bag. Then, 225 ml of modified Tryptone Soya Broth (TSB) supplemented with Novobiocin (mTSB+N) (1:9) was added to the raw beef and homogenized (Stomacher 400; Seward Medical, Worthing, United Kingdom) at high speed for 2 min. The enrichment sample was then incubated aerobically at 41.5°C for 24 h.

Isolation

All enriched broths were plated on to cefixime tellurite sorbitol MacConkey agar (CT-SMAC) (Oxoid, Basingstoke, England), supplemented with 0.05 mg/L cefixime and 2.5 mg/L tellurite (Oxoid, Basingstoke, England) (CT-SMAC) (Oxoid, Basingstoke, England) and incubated at 37°C for 24 h. After the incubation period, the CT-SMAC agar plates were examined for the presence of non-sorbitol fermenter colorless colonies, and subsequently, they were sub-cultured on Rainbow agar O157 (Hayward, Berkeley Heights, NJ, USA). The plates were then incubated for 20–24 h at 37°C and observed for the presence of typical black or gray coloration on Rainbow agar O157, indicating pure colonies (22).

FIGURE 1 | Sub-cities in Addis Ababa included in the study (20).

Biochemical Confirmation

Five typical colonies from each Rainbow agar O157 plate were sub-cultured on nutrient agar (Oxoid, Basingstoke, England) for biochemical confirmation by indole formation. The agar plates were incubated at 37°C for 18–24 h. One colony from the pure culture on nutrient agar was inoculated into a tube of tryptone/tryptophan medium (Oxoid, Basingstoke, England) and incubated at 37°C for 24 h. Then, 1 ml of Kovac's reagent (Oxoid, Basingstoke, England) was added and the tube allowed to stand at room temperature for 10 min. The formation of red color indicates a positive reaction (11).

Serological Identification of O157 and H7 Antigens

Indole-positive colonies were examined for their serological reaction with antiserum to *E. coli* O157:H7 using *RIM E. coli* O157:H7 latex test (Oxoid, Basingstoke, England). Indole-positive colonies were sub-cultured from the nutrient agar to the sorbitol MacConkey agar (Oxoid, Basingstoke, England). For every isolate to be tested, one drop of test latex was dispensed into a well of the test slide. In like manner, one drop of *E. coli* control latex was dispensed into a separate well of the test slide. Using a plastic stick, a portion of the non-sorbitol fermenting colony (NSFC) was removed from the sorbitol MacConkey agar (SMAC) (Oxoid, Basingstoke, England) plate and emulsified in *E. coli* O157 test latex on the slide and spread over the reaction area. Using a fresh plastic stick, the process was repeated with the remaining NSFC and emulsified in *E. coli* control, latex on the slide. The slide was rotated using circular motions for up to 1 min or until agglutination appears. For *E. coli* O157 positives that agglutination occurs with the *E. coli* O157 test latex and the control latex is negative, the isolate was streaked from sorbitol MacConkey agar (Oxoid, Basingstoke, England) to a blood agar (Oxoid, Basingstoke, England) plate and incubated at 37°C for 18–24 h. After 18–24 h incubation, the sweep of growth from the blood agar plate was emulsified in a drop of *E. coli* H7 test latex. Colonies giving an agglutination reaction were confirmed as *E. coil* O157:H7 positive.

Antimicrobial Susceptibility Testing

The antimicrobial susceptibility was performed, following the standard agar disk diffusion method consistent with CLSI (23) using commercial antimicrobial disks (**Table 1**). The antimicrobial agents were selected based on the use of antimicrobial agents in the ruminants, potential public health importance, and recommendations from the guideline of antimicrobial susceptibility testing from the Clinical and Laboratory Standards Institute (23).

Each isolated bacterial colony from pure fresh culture was transferred into a tube of 5 ml TSB (Oxoid, Basingstoke, England) and incubated at 37°C for 6 h. The turbidity of the culture broth was adjusted using sterile saline solution or added more colonies to get turbidity comparable with that of 0.5 McFarland standards. The diluted bacterial suspensions were swabbed in

TABLE 1 | Antibiotic disks used to test *E. coli* O157:H7 and their respective concentrations.

No.	Antibiotic disks	Disk code	Concentration	Diameter of zone of inhibition in millimeters (mm)		
				Resistant ≤	Intermediate	Susceptible ≥
1	Ampicillin	AM	10 μg	13	14–16	17
2	Amoxycillin-clavulanic acid	AMC	20/10 μg	13	14–17	18
3	Amikacin	AK	30 μg	14	15–16	17
4	Ciprofloxacin	CIP	5 μg	15	16–20	21
5	Ceftriaxone	CRO	30 μg	19	20–22	23
6	Cefoxitin	FOX	30 μg	14	15–17	18
7	Nitrofurantoin	F/M	50 μg	14	15–16	17
8	Kanamycin	K	30 μg	13	14–17	18
9	Nalidixic acid	NA	30 μg	13	14–18	19
10	Sulfamethoxazole- trimethoprim	SXT	25 μg	10	11–15	16
11	Tetracycline	TE	30 μg	11	12–14	15
12	Streptomycin	S	10 μg	11	12–14	15
13	Gentamicin	GM	10 μg	12	13–14	15

three directions uniformly on the surface of Mueller–Hinton agar plates using sterile cotton swabs. After the plates were dried (about 10 min), with the aid of sterile forceps, antibiotic-impregnated disks were placed to the surface of the inoculated plates. Then, the plates were incubated aerobically at 37°C for 24 h. Finally, the diameter of the inhibition zone formed around each disk was measured on a black surface using a transparent ruler by placing it over the plates. The results were classified as sensitive, intermediate, and resistant according to the CLSI (23). *E. coli* (ATCC 25922)-type strains were used as a positive control.

Multidrug Resistance (MDR)

Multidrug resistance (MDR) was defined as a resistance of a bacterial strain for at least one agent in three or more antimicrobial categories (24).

Ethical Consideration

The study protocol was ethically approved by the Institutional Review Board of Aklilu Lemma Institute of Pathobiology, Addis Ababa University (Minutes Ref NO: ALIPB IRB/006/2011/2018).

Data Management and Analysis

The data were entered and coded in MS Excel and then analyzed using IBM SPSS version 25.0 (25). The prevalence was determined by dividing the number of positive samples by the total number of samples examined. Descriptive statistics such as frequency and percentages were used to describe the proportion of resistant, intermediate, or susceptible strains. The difference in prevalence by sub-city was determined using the chi-square (χ^2) test. A p-value <0.05 was considered indicative of a statistically significant difference.

RESULTS

Prevalence

Out of 384 raw beef samples examined, 14 (3.64%) (95% CI = 1.77–5.51%) were positive to *E. coli* O157:H7 serotypes.

TABLE 2 | Prevalence of *E. coli* O157:H7 by risk factor.

Risk factor		Number examined	Positive no. (%)	X^2	*df*	*p*-value
Sub-city	Addis Ketema	50	1 (2)	13.039	9	0.161
	Akaki Kality	68	1 (1.47)			
	Arada	21	3 (14.29)			
	Bole	43	2 (4.65)			
	Gullele	14	1 (7.14)			
	Kirkos	29	2 (6.9)			
	Kolfe Keraneo	51	0 (0)			
	Lideta	29	2 (6.9)			
	Nefassilk	58	1 (1.72)			
	Yeka	21	1 (4.76)			

E. coli O157:H7 serotypes were detected in Addis Ketema (2%), AkakiKality (1.47%), Arada (14.29%), Bole (4.65%), Gullele (7.14%), Kirkos (69%), KolfeKeraneo (0%), Lideta (6.9%), Nefassilk (1.72%), and Yeka (4.76%). Variation in the prevalence between the butcher shops from the different sub-cities was not statistically significant ($p > 0.05$) (**Table 2**).

Antimicrobial Susceptibility Pattern

The result of the antimicrobial susceptibility test of the14 *E. coli* O157:H7 serotypes isolated from raw beef samples with 13 selected antimicrobial agents is shown in **Table 3**.

All the 14 *E. coli* O157:H7 serotypes' isolates from raw beef were found to be susceptible to amikacin (100%), ciprofloxacin (100%), and ceftriaxone (100%). Furthermore, the isolates showed high susceptibility to sulfamethoxazole-trimethoprim (92.8%), nalidixic acid (92.8%), gentamicin (85.7%), cefoxitin (78.5%), kanamycin (71.4%), and amoxicillin-clavulanic acid (64.2%). The results of the present study on antimicrobial

TABLE 3 | Antimicrobial susceptibility pattern of *E. coli* O157:H7 isolates ($n = 14$).

Antimicrobial used	Sensitive no. (%)	Intermediate no. (%)	Resistant no. (%)
Ampicillin (AM)	1 (7.14)	0 (0)	13 (92.8)
Amoxicillin-clavulanate (AMC)	9 (64.2)	2 (14.2)	3 (21.4)
Amikacin (AK)	14 (100)	0 (0)	0 (0)
Ciprofloxacin (CIP)	14 (100)	0 (0)	0 (0)
Ceftriaxone (CRO)	14 (100)	0 (0)	0 (0)
Cefoxitin (FOX)	11 (78.5)	2 (14.2)	1 (7.14)
Nitrofurantoin (F/M)	1 (7.14)	0 (0)	13 (92.8)
Kanamycin (K)	10 (71.4)	4 (28.5)	0 (0)
Nalidixic acid (NA)	13 (92.8)	1 (7.14)	0 (0)
Sulfamethoxazole trimethoprim (SXT)	13 (92.8)	0 (0)	1 (7.14)
Tetracycline (TE)	5 (35.7)	2 (14.2)	7 (50.0)
Streptomycin (S)	4 (28.5)	8 (57.1)	2 (14.2)
Gentamicin (GM)	12 (85.7)	2 (14.2)	0 (0)

TABLE 4 | MDR profile of *E. coli* O157:H7 isolates.

Number of antimicrobials	Antimicrobials	No. of isolates (%)
Three	AM,F/M,TE	3 (21.4)
	AM, F/M, AMC	1 (7.14)
	AM, F/M, S	1 (7.14)
Four	AM, F/M, AMC, TE	1 (7.14)
Five	AM, F/M, AMC, FOX, TE	1 (7.14)
	AM, F/M, S, SXT, TE	1 (7.14)
	Total MDR	8 (57.14)

AM, ampicillin; AMC, amoxicillin-clavulanate; FOX, cefoxitin; F/M, nitrofurantoin; S, streptomycin; SXT, sulfamethoxazole + trimethoprim; TE, tetracycline.

sensitivity test indicated high resistance to ampicillin (92.8%), nitrofurantoin (92.8), and tetracycline (50.0%).

Multidrug Resistance Profiles

Out of the 14 *E. coli* O157:H7 isolates, 8 (57.14%) were found to be resistant to three or more antimicrobial categories. MDR profiles against three, four, and five antimicrobial categories were resistant to 5 (35.7%), 1 (7.1%), and 2 (14.3%), respectively. The frequency of resistant phenotype was more common for ampicillin, nitrofurantoin, and tetracycline (**Table 4**).

DISCUSSION

Foodborne infections are major health concerns in developing countries including Ethiopia. The surveillance and monitoring of foodborne pathogens provide crucial information on planning, implementing, and evaluating food safety systems. Therefore, appropriate information on the contamination level and antimicrobial susceptibility of *E. coli* O157:H7 in retail raw beef may have implications in strengthening the surveillance system of foodborne diseases as well as is important to design prevention and control measures to decrease the risk of contamination. The prevalence of *E. coli* O157:H7 found in raw beef samples in the present study was 14/384 (3.64%) (95% CI = 1.77–5.51%). Similar to our findings, *E. coli* O157:H7 was identified in 1/25 (4%), 1/25 (4%), and 1/30 (3.3%) of raw beef samples at butcher shops in Addis Ababa, Batu, and Holetta, respectively (16). In contrast to our findings, the lower prevalence in raw beef samples was 3/150 (2%) in Hawassa and 1/125 (0.8%) in Addis Ababa and Debre Berhan (14, 15). Higher prevalence was described in butcher shops in Bishoftu 8/86 (9.3%) and 2/30 (6.7 %) and in Addis Ababa 14/64 (21.9%) (11, 12, 16). The variation of these findings might depend on different factors, e.g., abattoir, butcher conditions, sample size, and laboratory methods.

In this study, no statistically significant variation in the prevalence rate among the sub-cities butcher shops of beef samples ($p > 0.05$) was observed. This might be due to butcher shops sourcing their cattle carcasses from the main abattoir in the city. The small number of positives also means that a much larger sample size would be needed to identify any differences.

All of the 14 isolates of raw beef were susceptible to amikacin, ciprofloxacin, and ceftriaxone. Furthermore, the isolates showed high susceptibility to sulfamethoxazole-trimethoprim, nalidixic acid, gentamicin, cefoxitin, kanamycin, and amoxicillin-clavulanic acid. Similar findings have been reported by other researchers from Ethiopia (11, 12, 14–16, 18, 26). The *E. coli* O157:H7 strains isolated from raw beef had high resistance to ampicillin (92.8%), nitrofurantoin (92.8%), and tetracycline (50.0%). Similarly, studies from Ethiopia (13–16, 18, 26, 27) and Nigeria (27) revealed high resistance among *E. coli* O157:H7 isolates to ampicillin. However, 90% susceptibility of ampicillin was reported in Bishoftu (11). Nitrofurantoin resistance was reported in Somalia and Hawassa (13, 15). Drugs like ampicillin and nitrofurantoin have long been used for the management of various infections in Ethiopia, and high rate of resistance to these drugs might have developed as a consequence of this prolonged use (28).

Moreover, the findings of antimicrobial susceptibility test showed that 50% of *E. coli* O157:H7 isolates from raw beef resistance to tetracycline (14, 17). This is in agreement with previous studies from Ethiopia (11, 13, 26, 27) and Nigeria (27). This might be related to the broad use of tetracycline in the management of various infections in the livestock in Ethiopia (29).

Among the 14 *E. coli* O157:H7 isolates from raw beef tested, 8 (57.14%) were resistant to three or more classes of antibiotics. The occurrences of multidrug-resistant isolates (17.9–92.5%) were also reported in previous studies in Ethiopia (11–13, 17, 18). The occurrence of MDR may be associated with indiscriminate utilization of antimicrobial agents, which was not elucidated with the current study method. Furthermore, the transmission of MDR bacteria *via* the consumption of meat have been propounded as a potential source in Africa (30, 31).

The present study had some limitations. The use of immunomagnetic separation (IMS) with enrichment in broth culture enhances the isolation of *E. coli* O157 from samples with a low concentration of bacteria (32). In this study, enrichment without IMS was employed to isolate *E coli* O157:H7. Nevertheless, the present study revealed that multidrug-resistant *E. coli* O157:H7 were present in raw beef sold in butcher shops

in Addis Ababa, Ethiopia. Given the low infective dose of *E. coli* O157:H7 [10 colony forming unit (CFU)/g] and the cultural habit of eating raw beef in the society, the current prevalence should be considered important from a public health standpoint. These findings should be communicated with government and projects working with butchers along with the information on reducing the risk. Thus, more stringent monitoring of antimicrobial use in both human and animal populations should be implemented. In addition, further studies should be conducted to understand the *E. coli* O157:H7 points of contamination and define appropriate risk mitigation strategies.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

AH: conceived and designed the study, conducted the study, analyzed the data, and wrote the paper. SA: conceived the study, provided guidance to its design, and reviewed the manuscript. NB: designed the study, analyzed the data, and wrote the paper. TA: conducted the study and analyzed the data. PB: reviewed the paper and wrote the paper. DG: conceived and designed study, analyzed the data, and reviewed the manuscript. All authors contributed to the article and approved the submitted version.

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Stakeholders' Knowledge, Attitude, and Perceptions on the Control of *Taenia solium* in Kamuli and Hoima Districts, Uganda

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Taenia (T.) solium is a zoonotic parasite causing three diseases: Taeniasis and cysticercosis in humans and porcine cysticercosis in pigs. Although biomedically, the transmission of the parasite can be easily interrupted at six points along the life cycle, the contextual factors that may influence the adoption of these control strategies in Uganda remain unclear. This study assessed the stakeholders' knowledge, attitudes, and perceptions relating to the six control strategies for *T. solium* infections in Kamuli and Hoima districts, Uganda. A total of 22 focus group discussions (FGD) were conducted with pig farmers, community leaders, pig/pork traders, animal health assistants, and human health assistants. In addition, nine key informant interviews were held with senior officials in the ministries of agriculture and health and other relevant agencies at the district level. The results showed differential, limited, and fragmented knowledge on *T. solium* infections among stakeholders. Pig farmers, community leaders, and pig/pork traders had almost no knowledge and were often confused regarding the differences existing between *T. solium* and other gastro-intestinal infections in pigs and humans. Pig confinement, pit latrine construction, coverage, maintenance, and sustained use are influenced by cultural, socio-economic, and physical/ environmental factors of the study population and area. Proper sensitisation programmes and health education interventions should target all, but with appropriately focused material to suit the different stakeholder categories. Reminders or nudges may be needed to ensure that increase in knowledge translates to changes in practise. Intervention programmes should also aim to overcome challenges created by the various contextual factors operating in the specific endemic areas.

Keywords: ***Taenia solium*, control strategies, knowledge, attitudes, perceptions**

INTRODUCTION

The local demand for pork has significantly driven growth in pig production in Uganda since the 1990's (1, 2). Around 70% of the pork produced in Uganda is consumed domestically at roadside butcheries and eateries, commonly known as pork joints (3). The majority of pigs are raised by smallholder farmers who are resource-constrained and rear pigs extensively with little investment in housing and feeding (4). Many of the pigs are either tethered or intermittently housed, depending on seasonality. They are fed mostly on crop residues (5). The rural areas in Uganda are also characterised by low coverage and underuse of sanitation facilities (6), creating a suitable environment for the transmission of *Taenia* (*T.) solium*.

The *T. Solium* is a zoonotic parasite causing three diseases: Taeniasis and cysticercosis in humans, and porcine cysticercosis in pigs. Taeniasis is the presence of adult tapeworms in the intestines of humans due to the consumption of undercooked pork containing viable cysts. In pigs, the ingestion of the tapeworm eggs from the environment leads to the development of cysticerci in the striated muscles, a condition known as porcine cysticercosis (PCC). Humans can also be infected by cysticercosis after ingestion of the tapeworm eggs shed by themselves or other humans. If the cysticerci lodge in the central nervous system, it leads to neurocysticercosis (NCC), a disease of serious health and social burden (7–9).

The transmission of the parasite can be interrupted at six points, along with the life cycle, as simplified in the *"Lets break the pork tapeworm cycle*" poster (10). These include: (1) use of toilets, (2) washing of hands, fruits, and vegetables, (3) regular deworming of children and adults, (4) pig confinement, (5) proper meat inspection, and (6) proper cooking of pork (10). In order to reduce the burden of NCC, three control strategies have also been proposed and tested for effectiveness at the community level in different endemic settings, including mass drug administration (MDA) of praziquantel to control taeniasis in humans (11), vaccination of pigs with TSOL18 vaccine combined with treatment using oxfendazole (12), and health education (13, 14). The success of the different control strategies may be influenced by contextual factors operating in target areas, including socio-economic, cultural, geographical, and environmental factors (15).

In Uganda, the socio-economic, cultural, and other factors that may influence the adoption of the six control strategies aimed at disrupting the transmission of the parasite have not been studied. The study, therefore, aimed to determine the knowledge, attitude, and perceptions of different stakeholders on the control of *T. solium* in the Kamuli and Hoima districts in Eastern and Western Uganda, respectively.

MATERIALS AND METHODS

Ethical Statement

Ethical clearance was obtained from the International Livestock Research Institute's (ILRI) Institutional Research Ethics Committee (ILRI-IREC), reference number ILRI-IREC 2019-20 with extension reference number ILRI-IREC2019-20/2, respectively. Since the study was conducted in Uganda, approval was also obtained from the Research and Ethics Committee at the College of Veterinary Medicine, Animal Resources and Biosecurity, Makerere University (reference. SBLS/HDRC/19/008), along with a research permit obtained from the Uganda National Council for Science and Technology (reference A606). Before the start of the meetings, consent to participate and allow recording of the discussion was sought from both the focus group discussion (FGD) and key informant interview (KII) participants, and all of them signed an informed consent form. A consent form translated into the local language was explained to those unable to read and write, and they confirmed participation by inserting a thumbprint on the consent form.

Study Area

The study was conducted between March and April 2021 in the Kamuli and Hoima districts, Uganda (**Figure 1**). These districts have high numbers of pig rearing households and high demand for pig meat and pig products Ouma et al. (16). The districts of Kamuli and Hoima were chosen because they have been sites for the International Livestock Research Institute (ILRI)-led research on the pig value chain. This made entry into the study site easy because local stakeholders had already established contact. The pig value chain of the districts had also been previously well-characterised Asiimwe et al. (17), Ouma et al. (2). In each district, community participants were drawn from villages within three sub-counties. However, the central government ministry official participants were drawn from across the districts.

Study Design and Selection of Stakeholders

A community-based, qualitative study design was used. The FGDs comprising of 8–10 participants and KII were used to collect qualitative data. Different stakeholder categories play different roles in *T. solium* control. Therefore, the FGDs were organised by stakeholder category. The FGDs and KIIs were conducted as per the identified stakeholder categories shown in **Table 1**. To identify the stakeholders, a preliminary list was generated based on the pig value chain scoping visit conducted in 2014 under the smallholder pig value chain development project led by ILRI (18). The researcher then visited the two sites (the Kamuli and Hoima districts) to identify the specific stakeholders, explain the project, and check their availability to participate. For the pig farmer stakeholder category, separate FGDs were held for men and women. This was done to ease the collection of information across gendered toilet use and cleaning, maintenance, and pork preparation practises. Ten community leaders from each district were randomly selected from a list of 30 village leaders from villages that participated in an earlier cross-sectional study in 2019 (19). For farmers, the participants were randomly selected from a list of pig farmers who participated in the cross-sectional study in 2019 (19). The random function in excel was used for the randomisation. A maximum of 10 participants per category were invited for the FGD to ensure social distancing as per corona virus disease 2019 (COVID-19) pandemic protocols.

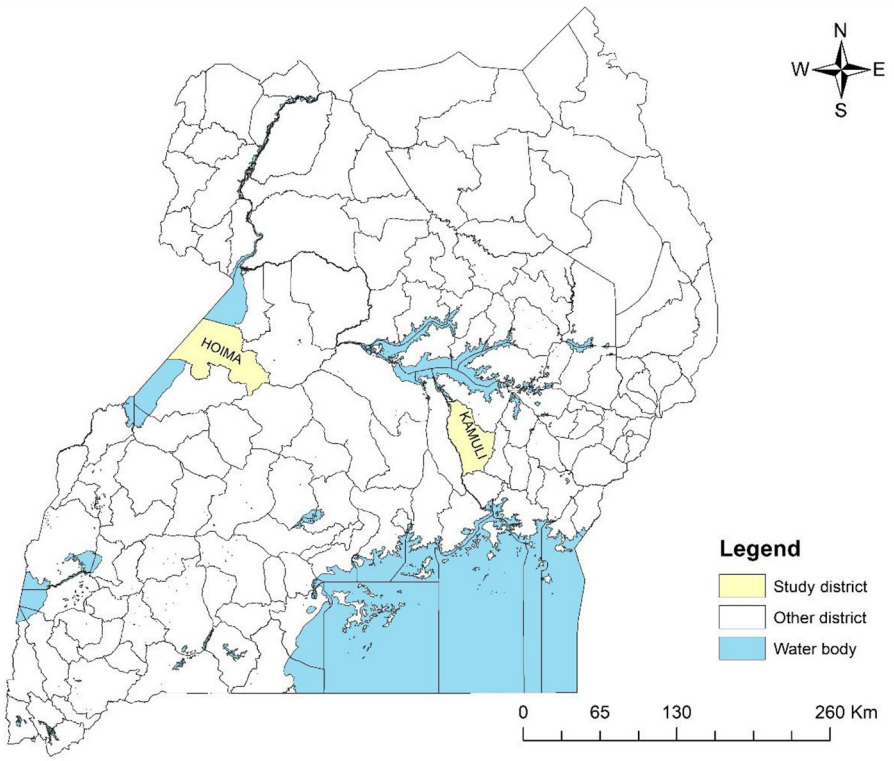

FIGURE 1 | Map of Uganda showing the study districts (shaded in yellow).

Data Collection and Management

An FGD and KII checklist was developed, along the six points, where the transmission of *T. solium* can be interrupted in its life cycle as outlined in **Figure 2**. The FGD and KII guides were pretested in the peri-urban areas of Kampala with the different stakeholder categories. Changes were reviewed by the study team and adjustments were made to the guides.

Data were collected by 2 facilitators who were fluent in Runyoro/Runyankole (the local language in Hoima) and Lusoga (the local language in Kamuli), with one acting as a moderator and the other as a note-taker who captured non-verbal aspects of the discussion, i.e., hand counts, while supporting the moderator with timekeeping and in the case that some aspects of the guide were omitted. The FGDs with the ministry officials were conducted using both English and the local language understood by the participants. The KIIs were exclusively conducted in English by the lead researcher. All the FGDs and KIIs were audio-recorded using an electronic recorder. The audio files were transcribed verbatim into English by transcribers fluent in Runyoro/Runyankole and Lusoga languages. The typed scripts were verified by listening to audio files and comparing them with the notes. A coding frame was first developed by the lead author (NN) using prior knowledge on the control of *T. solium* based on the poster described earlier. The data were then coded into the respective codes or themes. The data were analysed using the deductive content analysis (20) and aided by NVIVO version 12 (21).

RESULTS

After a description of the demographic characteristics of the participants and their knowledge of *T. solium*, the results section is then divided into sections, along with the six points, where the transmission of *T. solium* infections can be interrupted.

Demographic Characteristics

A total of 210 discussants participated in 22 FGDs that comprised of 12 FGDs with pig farmers, two FGDs each with animal health assistants, human health assistants, community leaders, and pig/pork traders. For the pig farmers, six FGDs were conducted in each district, and one FGD in each district for the other stakeholder categories. Nine more KIIs were conducted in both the Kamuli and Hoima districts, three with district veterinary officers, two with district health officers, one with a veterinary officer working for a local catholic relief organisation in Hoima, one each with a local private company in Hoima, the Neglected Tropical Diseases focal person under the vector control division of Ministry of Health in Kamuli, the head of the community breeding programme for National Animal Genetic Resources Centre and Data Bank (NAGRIC & DB), and the director of Iowa State University Uganda programme (https://www.globe.iastate.edu/global-experience/extension-projects-uganda/). Two FGDs were also conducted with leaders of local pig farmer associations in the Kamuli and Hoima districts. A full list of FGDs and KIIs can be found in **Table 1**. In total, 57 men and 59 women

TABLE 1 | Stakeholder categories targeted for data collection and their description.

Stakeholder category	Description/target person or group	Relevance to *T. solium* control	Method for data collection
Pig farmers	Pig farmers randomly from a list of pig farmers from 30 villages	They are responsible for control of the parasite at the intermediate and final host stage by practising proper hygiene and good pig husbandry.	FGD
Community leaders (LC1)	Selected randomly from villages across 3 sub-counties	They are village leaders and are the link between national government administration and community. They are involved in enforcing latrine use and other bylaws within the village.	FGD
Animal health assistants	Purposively invited through the District veterinary officer and were drawn from the different sub-counties in the district.	They oversee meat inspection and promotion of good animal husbandry at sub-county level.	FGD
Human health assistants	Purposively selected and invited through the District health officer and were drawn from the different sub-counties in the district.	They oversee human health activities in a sub-county and act as the heads of level 3 health facilities (the government health facility at the sub-county level	FGD
Pig/pork traders	Selected by snowballing from different sub-counties within the district starting from the district headquarters. Three traders were picked from each sub-county.	They buy pigs from farmers and operate butcheries and pork joints at the sub-country level where they sell raw and ready-to-eat pork.	FGD
District veterinary officers (DVO)	One officer from each district of study. Hoima district was recently subdivided in to 2 and therefore 2 DVOs were included.	They oversee veterinary and animal production in the district including meat inspection.	KII
District health officers (DHO)	One officer from each district of study (1 from Kamuli and 2 from Hoima district).	They oversee human health activities in the district including promotion of community hygiene.	KII
Private company (Devenish Nutrition in Hoima)	Outreach officer	The private company is involved in training of farmers and sale of inputs to pig farmers.	KII
Catholic NGO (HOCADEO-Hoima)	Veterinary extension officer	They are involved in promotion of pig husbandry and general household hygiene including toilet construction	KII
Neglected Tropical disease focal person under vector control division Ministry of Health–Kamuli	One official in Kamuli	They oversee mass drug administration campaigns in the district to control schistosomiasis. Praziquantel which is the drug of choice also treats taeniasis.	KII
National Animal Genetic Resources centre and Databank (NAGRIC & DB)	Head of community breeding programme	They are involved in extension work promoting improved pig husbandry.	KII
Iowa state university Uganda programme	The head of programme in Kamuli field office	They are involved in extension work promoting improved pig husbandry as well as household nutrition.	KII

pig farmers attended the FGDs in both the Kamuli and Hoima districts. The demographic characteristics of the participants are presented in **Table 2**.

Knowledge and Awareness on *Taenia solium* Infections

During the FGDs with the various stakeholders, it was established that there were differential levels of knowledge on *T. solium* and its control. Among the pig farmers, there was generally poor knowledge and awareness about the pork tapeworm. The majority of the farmers thought that the pork tapeworm is a type of worm infection that is found in the stomach or intestines of pigs, whereas the parasite manifests as small cysts within the musculature.

> *"The tapeworm is found in the stomach [of pigs]; it affects the intestines of the pigs leading to stunted growth. The tapeworm is white and lives around the intestines"* - F10, women FGD, Hoima district.

Some of the farmers described the worm as being whitish. However, some participants were fully aware and had also seen the tapeworms in the faeces of children.

> *"It manifests in humans. When defecating you can easily identify that a child has tapeworm after he has defecated"* – P3, Men FGD, Kamuli district.

Similarly, pig/pork traders and community leaders in both districts had poor knowledge on the pork tapeworm

FIGURE 2 | The "let's break the pork tapeworm life cycle" poster: source (10).

manifestation in pigs, although the majority agreed that pigs get infected when they roam around and feed on dirt, including soil, they considered it as a gastrointestinal worm.

> *"Tapeworms are small, and they affect pigs if they are not treated"* – *R4* pig trader, Hoima district.
>
> *"The tapeworm we are talking about is white in color and it looks like a round tapeworm, and it is elastic. When it is in an animal, especially the pigs, it makes it stunted, with swollen stomach"*. - P1, Community leaders, Kamuli district.

Many of the discussants in the animal and human health assistants' stakeholder category showed good knowledge of the *T. solium* infections, although some could not clearly link the tapeworm to human neurocysticercosis. The KIIs with the district veterinary and health officers showed that they had good knowledge and understanding of *T. solium* infection. The other four KIIs (local catholic relief organization veterinary officer in Hoima, local private company in Hoima, the Neglected Tropical Diseases focal person in Kamuli, and the head of community breeding programme for NAGRIC & DB) did not have comprehensive knowledge on the parasite, but they identified it as being a zoonotic parasite.

Pig farmers believed that pork tapeworm infections occur in pigs due to consumption of raw sweet potatoes, cassava peeling, or generally dirty and soiled feeds, and when the pig scavenges as it roams. Although farmers recognised that people acquired infections by eating foods or drinking water contaminated with faeces, there was confusion with the majority alluding that infection in humans can be through contact, sharing personal items or through the eggs penetrating the skin on the feet, implying threadworms. There was also a belief that it could arise naturally or automatically without any specific cause.

> *"If an infected person defecates in the open environment, the feaces can be taken by running water to water sources and the egg if that water is taken un-boiled, the human being gets the tapeworms"* – *R9*, men FGD, Hoima district.

The above statement is wrong since ingestion of eggs results in human cysticercosis rather than tapeworm infection.

> "*I think it's somebody's nature to have tapeworms [. . .].. Whenever you deworm them, the tapeworms come out so it's his nature to have those tapeworms"*. – R5, Women FGD, Kamuli district.

TABLE 2 | Demographic characteristics of the study participant categories.

Demographic characteristics (numbers)		Kamuli	Hoima
Number of FGD	Men pig farmers	3	3
	Women pig farmers	3	3
	Animal health assistants	1	1
	Human health assistants	1	1
	Community leaders	1	1
	Pig/pork traders	1	1
Number of FGD participants	Men pig farmers	28	28
	Women pig farmers	29	31
	Total	57	59
Key informants (male and female)	Animal health assistants	10	8
	Human health assistants	10	10
	Community leaders	10	9
	Pig/pork traders	10	9
Pig farmers' level of education (%)	None	5.6%	0.0
	Primary	57.4%	45.8%
	Secondary	37.0%	44.1%
	Tertiary	0.0	10.2%
Pig farmers' mean age (in years)	Men	44.3	45.7
	Women	44.3	40.7
	Combined	44.3	43.2
Mean number of pigs		3.3	4.5

The discussants in the animal and human health assistants' FGD had good knowledge and understanding of the infections in humans and pigs. The community leaders also had good knowledge of the infections, but they had poor knowledge of the route of infection.

> *"Human beings get infected by tapeworms through eating unwashed raw fruits like mangoes and uncooked sweet potatoes. If a human being steps on the feaces of an infected person with the eggs of the tapeworm, they also get infected"* – R6, community leaders, Hoima district.
>
> *"The pigs are the intermediate host. Human beings are the final hosts"* – R5, Animal health assistants, Hoima district.

Latrine Construction, Coverage, and Use

Discussants in the farmers' stakeholder category estimated the pit latrine coverage (i.e., households having toilets in their homesteads) in their villages to be over half. However, the majority agreed that half were in bad condition–lacking complete walls, a door, or a roof. The estimate by the human health assistants who were promoters of community hygiene was not different. In both districts, the human health assistants estimated the coverage to be slightly above half, with less than half having permanent structures. The discussants in the community leaders' category from both districts gave the highest estimate of latrine coverage. The human health assistants noted that in both the districts, the sub-counties along flood-prone areas like the banks of river Nile in the Kamuli district and the shores of Lake Albert in the Hoima district had low latrine coverage due to occasional flooding. Those without latrines were reported to use their neigbours' latrines or use a polythene bag to later throw, especially those in urban areas, go with a hoe and dig a hole in the farm to defecate in, or defecate in banana and/or sugarcane plantations or in nearby bushes.

Most of the latrines were reported to be semi-permanent structures constructed using locally available materials such as tree logs and grass, while the permanent ones were constructed using commercial materials like cement, bricks, and iron sheets. According to the community leaders in both districts, half of the households had semi-permanent structures, of which some were without doors, walls, roofs, and had poorly constructed slabs that made them difficult to use. The design of the latrines was determined by the availability and cost of construction and construction materials.

> *"2/10 households have permanent latrines, and 5/10 households have semi-permanent latrines while 3/10 have latrines without shelters [wall and roof]. Some households dig the pit and put the slab and do not put the shelter"* – R5, Community leaders FGD, Hoima district.
>
> *"Most of them are made of grass, mud, poles, and reeds"* – R1, Human health assistants, Hoima district.
>
> *"They are permanent and temporary, and these are made of cement, bricks, iron sheets, gravel, sand, tiles and pipes"* – R6, Human health assistants, Hoima district.

Several barriers to pit latrine construction were identified. Many participants cited the lack of resources to buy building materials as the main challenge in latrine construction. Other challenges included lack of construction equipment (hoes and spades), lack of space to construct the latrine, weak soils, rocky areas, which made digging hard, high-water table, especially along the flood plains, traditional norms, and customs that inhibited older generations from constructing latrines in the earlier years.

> *"Most people lack resources such as money and the materials for the construction of latrines"* – R2, Men FGD, Hoima district.

Also, ignorance on the importance of having a latrine was cited by the participants. In Hoima, pig farmer discussants noted that they had formed a group to help them mobilise resources for buying materials, digging, and constructing pit latrines as a group.

> *"Some soils are weak making them break so fast. The costs of constructing latrines are high. And some soils are rocky making it difficult to dig pits"* – R5, Human health assistants, Hoima district.

For the semi-permanent latrines that were made using non-commercial materials, the role of men was to dig the pit, cut logs, and build the latrine. On the other hand, women supported the construction by cutting grass for thatching and fetching water. In terms of maintenance, most of the farmers agreed that women cleaned the latrines using brooms and ashes, trained the children on pit latrine use, and enforced latrine

use. On the other hand, it was noted that, in most cases, the household head funded the construction of permanent latrines and paid for the mason.

At the community level, enforcement of pit latrine construction and promotion of household hygiene was reported to be carried out by the community leaders and village health teams (VHTs). The VHTs are village-based structures whose members are selected through a popular vote by the community members to promote their health and wellbeing. One member is selected from 25 to 30 households and is supported by the ministry of health, Uganda (22). Overall, this role was identified by discussants in the farmers, community leaders, traders, and human and animal health assistants' stakeholder category. This was also supported by the KIIs with the district health officers in both districts.

> *"The village health teams [VHTs] and LC1[community leaders] do enforce the use of latrines in the villages. The LC1 work hand in hand to teach people about the importance of using a latrine"* – F8, Women FGD, Hoima district.

Barriers to Latrine Use

Several barriers to latrine use were cited by the majority of the discussants from the farmers, community leaders, traders, and human and animal health assistants' stakeholder category. The barriers included:

(i) Age: Children below 5 years and the elderly, e.g., people above 65 years (23), did not use pit latrines as identified by the majority of farmers and community leaders. The children defecate around the latrine and the faeces were thrown in the latrine or the garden. The elderly dug a hole in the garden and defecate or defecate in bushes or sugarcane plantations. The toilets are mostly pit latrines that require users to squat and, thus, handicap the elderly. Those rendered weak by ill health were reported not to use them.
(ii) Poorly constructed latrines with weak slabs or openings that made people fear falling into the pit, as identified by some farmers and the community leaders.
(iii) Poor lighting in the latrines prevented their use at night out of fear of rodents and snakes.
(iv) Poor state of hygiene and crowding in public latrines during public functions or market days.
(v) Smelly latrines.
(vi) Wrong intentions for construction of latrines, where some construct latrines to be seen by enforcement officers to avoid punishment. Additionally, others constructed the wall and roof without the pit just to trick enforcement officers.
(vii) Cost minimisation led to fear of using the toilet to avoid getting it full and having to construct another one.
(viii) Drunkards and mentally disabled people were reported not to use latrines.
(ix) Beliefs such as:

   a. Women should not use latrines. Otherwise, they will never bear children;
   b. Pregnant women should not use latrines;
   c. Children's feaces should not be thrown in latrines as they are not harmful and will decompose when thrown in the garden.

Handwashing and Personal Hygiene

The majority of the discussants in the farmer's and community leaders' stakeholder category noted that handwashing facilities were available near the latrine or in the compounds, usually in form of a foot-operated, small jerry-can ("tippy tap"), and in some cases, with available soap. It was also pointed out that this had become more common and adopted due to the ongoing campaign occasioned by the current COVID-19 pandemic.

> *"People have learnt to have these jerry-cans for washing hands because of the COVID-19 outbreak but way back people never mind having a handwashing facility"* – P3. Men FGD, Kamuli district.

Although most households were reported to have had handwashing facilities, the community leaders noted that few people washed their hands after using the latrines. The community leaders and VHTs were involved in promoting and sensitising households on good hygiene, including the use of latrines and having a handwashing facility. The KIIs with district health officers pointed out that control of *T. solium* infection can be achieved by ensuring proper sanitation, including handwashing, in households, but the practise is not widespread.

> *"When you are moving around, you find handwashing facilities. 7/10 households have handwashing facilities but only 2/10 households wash their hands after using the latrine"*- R5, Community leaders FGD, Hoima district.

Deworming of Children and Other Household Members

Discussants amongst the farmers' stakeholder category had different views on when themselves or children should be dewormed, with some indicating that deworming should happen every 2, 3, or 4 months or once a year. The majority reported that they dewormed using ketrax tablets (levamisole), albendazole, or mebendazole, with a few using local herbs. The deworming drugs were either bought at a local drug shop, private clinic, or issued for free at government health facilities, especially to expectant women during the normal antenatal visits. The majority of the different stakeholders reported that there were no government deworming programs targeting the general population. Despite this, in some of the sub-counties, there were school deworming programs for school-age children (SAC). The majority of the discussants belonging to different stakeholder categories were aware of the existence of mass deworming programs targeting SAC to treat soil-transmitted helminths (STHs). Some of the discussants from the farmers' stakeholder category noted that they did not know that adults can get worm infections and thought that it is only a problem in children.

"I did not know that even an adult person deworms, I knew children alone deworm. Government deworms children below five years" – R1, Men FGD, Hoima district.

However, it was noted that expectant mothers were issued with deworming drugs during routine antenatal visits to the government health facilities. The human health assistants also noted that school health days were organised twice a year in both districts to promote children's health and deworming. According to the community leaders, deworming of children was also done during routine immunisation campaigns in the communities. The Iowa State University Uganda program had clinic days, where they invited local health centres to sensitise the general community on good nutrition, during which deworming was also offered as reported by the KI interview with the director of the programme.

Confinement of Pigs

Pig farmers appeared to have knowledge that housing pigs has benefits, including prevention of diseases like African swine fever (ASF) and worm infections, and avoiding conflict with neighbours if the pigs roam into their farms. However, most of the farmers and community leaders noted that there were free-roaming pigs in their respective villages. Some farmers also confined pigs during the rainy season and let them roam during the dry season. The reasons for not housing pigs included: (i) lack of resources to construct pig pens, (ii) weak structures that were easily broken down by the pigs (iii) insufficient time available for their owners to care for housed pigs and attend to other business, thus, pigs were left on their own to roam and forage for feed, and (iv) pig feeds were also reported to be expensive, therefore, farmers preferred to leave the pigs to scavenge for feeds. Additionally, some farmers believed that free-roaming pigs grew faster as compared to confined pigs.

The animal health assistant discussants noted that the adoption of improved pig husbandry by farmers, including pig confinement, was moderate. They noted that the farmers put up simple structures because they had not taken pig rearing as a business venture. Despite this, some who had been trained and have been exposed to improved pig husbandry had good pig pens. The discussants also noted that farmers are discouraged from investing in pig housing because there are no price incentives for fat and well-reared pigs. The middlemen and traders preferred extensively reared small pigs because they obtained them at lower prices from the farmers. Moreover, because of low pork meat, traders buy small pigs that they can sell within 1–2 days due to the demand and lack of refrigeration in the rural areas.

"The market dynamics have discouraged farmers from adopting good husbandry. The middlemen always prefer cheaper pigs than the expensive ones" – R5, Animal health assistants, Hoima district.

Meat Inspection

The majority of the discussants in the farmers' stakeholder category noted that inspection in the villages was not regular and was usually majorly conducted by a government official during holiday seasons, such as Christmas, when a lot of pigs were slaughtered. The majority of the farmers also noted that as consumers, they did not check meat for cysts because they did not know how to or what to check. The farmers also noted that the traders do not allow consumers to inspect the meat by touching it. When buying raw pork, they only check for the colour, amount of fat, the freshness of the meat, whether it is from a male or female pig (meat from female pigs is preferred because it was considered soft), and the general cleanliness of the butcher. The majority of the traders did not inspect for cysts when buying the pigs because they did not know how to check for cysts, but they checked for signs of ASF and mange infections in live pigs.

"The responsible people [government official] don't inspect meat during the other normal days but rather they come during holidays when they know they are going to get a lot of money collections" – R1, Women FGD, Hoima district.

The traders relied on the government meat inspectors, who at times failed to reach their slaughter place, for meat inspection. In those cases, they would go ahead and sell uninspected pork, but it was reported by one of the traders that while local consumers do not demand to see a meat inspection stamp, consumers from Kampala do. The discussants also noted that if the meat inspectors arrived late, they inspected the meat while it is already in the butchery being sold. Many of the discussants of the animal health assistants/meat inspectors' stakeholder category noted that there is a lack of centralised slaughter facilities that exposed them to harassment by disgruntled butchers if they condemned carcasses during the inspection. Carcasses were, therefore, rarely condemned. Meat inspectors instead reported that they issue stamps with conditions that meat is properly cooked or only condemned the infected part of the carcass.

"[…]some of our customers from Kampala ask for the meat inspection stamp, we do not wait for him [meat inspector] we go ahead and sell uninspected pork. Some veterinary doctors come late, we sell and when she comes, she inspects as we are selling" – R1, Trader FGD, Hoima district.

"We lack facilities to do that, and we are not protected. Not only that there is no disposal site even if it is cattle carcass. So ideally, we lack are no facilities to burn it and even if you condemn, the meat still comes back to the market." – R1 Animal health assistants FGD, Kamuli District.

There was also political interference reported in terms of enforcement of the meat inspection laws. For instance, traders used political influence to prevent meat inspection from being conducted and evade enforcement. The participants in the KIIs with district veterinary officers (DVOs) noted that meat inspection is covered under the public health act of Uganda, but enforcement was constrained by lack of resources for transport to slaughter places, understaffing, lack of centralised slaughter facility, and political interference.

Pork Preparation

The majority of farmers identified butcheries and pork joints as being the main sources of raw and cooked (ready to eat) pork. In some rare circumstances, households were reported to have bought a pig to be slaughtered and shared, especially

during festivities. It was also reported that women were mainly responsible for preparing pork at home for consumption by household members.

Preparation of pork meat for consumption was done in several ways as was identified by the pig farmer FGDs discussants: (i) boiling to remove excess fat, adding ingredients like onions and tomatoes before frying; (ii) Roasting over wire mesh, cutting into small pieces, adding of ingredients, and frying until it is soft; and (iii) frying until it is well-cooked as indicated by a change in colour from white to brown. The majority of the discussants in the farmers' category reported that the barriers to cooking pork meat well at the household level included lack of enough firewood, impatience while cooking, lack of sufficient time to properly cook the meat, lack of awareness on the consequences of eating under-cooked pork, and the preference for under-cooked pork. When the pork was consumed in the pork joints, the consumers relied on the butchers to tell when pork is well-cooked or roasted.

Most of the discussants in the pork traders' stakeholder category noted that the barriers for them to cooking or roasting pork in their pork joints included: (i) lack of firewood for cooking/roasting, (ii) too many orders from customers, (iii) lack of awareness on the consequences of eating under-cooked pork, (iv) lack of roasting or cooking skills, (v) lack of utensils for cooking/frying like saucepans, and (vi) the preference of some customers for under-cooked pork. The majority of the discussants in the pig farmers' stakeholder category noted that eating poorly cooked pork could lead to vomiting, stomach pain, and diarrhoea. In the Kamuli district, it was noted that the consumption of raw pork leads to swollen cheeks. In the Hoima district, a few of the discussants said it led to brucellosis. None of the discussants among the pig farmers' category mentioned that it could result in infection with pork tapeworm.

DISCUSSION

Among the various type of stakeholders targeted, pig farmers, community members, and traders' categories had the lowest level of knowledge, specifically on *T. solium* infections. Similar findings were reported in Northern Uganda (24). There was a confusion of the pork tapeworm with other pig gastrointestinal helminths, with results similar to those reported in Eastern Zambia (25). This could be due to how farmers could easily identify infection of pigs with worms through physical symptoms such as stunted growth, reduced weight gain, emaciation, and identification of the nematodes in pig faeces. Pig gastrointestinal parasites are prevalent in Uganda and have been extensively reported in various locations including in the Kamuli and Hoima districts (19, 26, 27).

A limited number of participants were aware of tapeworm infection in children but not in adults. Taeniasis could be due to infections with either *T. solium* or *T. saginata,* neither of which have been well-studied in human populations in Uganda. Only one study reported a prevalence of 0.7% for taeniasis among school children in Kampala (28). As the participants could not clearly describe the worms seen in the faeces, they could have been other intestinal helminths reported in school-going children in Uganda (28, 29). Knowledge on the tapeworm was highest among human and animal health professionals albeit with confusion on how the infection with *T. solium* leads to neurocysticercosis. Similar findings were reported in Tanzania among veterinary extension officers and medical health professionals (30).

The infection of pigs with *T. solium* cysticercosis does not produce any identifiable clinical signs and may persist unnoticed in pigs. However, in contrast with findings of the current study, Kungu et al. (31), using a household survey, reported a high knowledge performance score of farmers on *T. solium* infection transmission in Eastern and Western Uganda. On the other hand, low knowledge levels on *T. solium* transmission in the general population have been reported in Tanzania (32). One limitation of these studies is that they used a "yes/no" knowledge question implanted in a household survey that may have not brought out the true underlying knowledge levels. Low awareness and knowledge on *T. solium* infections and transmission reported in this study may be a barrier to the adoption of practises aimed at breaking the transmission cycle and reducing the incidence and prevalence of the infections.

Although there was reportedly a relatively high pit latrine coverage in the study districts, many of the toilets were poorly constructed. The national latrine coverage in Uganda stood at 79% in 2018, with 3 out of 10 households lacking a latrine (33, 34). The high cost of toilet construction may have led to the construction of low-quality latrines with weak slabs or ones with large spaces between the poles on the floor, incomplete walls, or roofs. Latrine construction was also affected by the state of the ground, e.g., rocky, loose, or sandy soils, and high-water tables in areas along the flood plains, making it difficult for construction. Similar challenges due to soil formations were reported in Ghana (35). Günther et al. (36) noted that lack of money was the major barrier to investment in latrine construction in Uganda. The cost of constructing a ventilated pit latrine with a plastered brick structure was estimated at USD 760 in peri-urban Kampala (37). The median monthly wage for the rural population in Uganda was estimated at UGX 120,000, approximately USD 33 (at USD 1 = UGX 3,600), and UGX 220,000, approximately USD 61, for the urban population in 2016 (38). This may mean that majority of households may struggle or may be unable to construct a modern toilet given the estimated cost with this income level.

During latrine construction, men and women played different roles, with men taking up more physical activities like digging the pit, while women supported construction by fetching water and thatching materials. Nunbogu et al. (35) made similar observations in Ghana. Additionally, women were responsible for toilet maintenance, cleanliness, and latrine use enforcement. Dissemination of information and enforcement of latrine construction and use without capital investments may not be sufficient to increase coverage and sustained use. Furthermore, gendered roles on latrine construction use and maintenance should be considered when designing interventions to increase pit latrine coverage and use.

Although relatively high latrine coverage was reported in the current study, as was also estimated by the government of Uganda at 79% (33), open defecation, which is a risk factor for *T. solium* cysticercosis and other infections, was still reportedly practised, especially by the elderly, children, and, in some instances,

other household members. Similar findings were reported in a systematic literature review on latrine coverage and use by Garn et al. (39), who noted open defecation even among households with latrines.

Open defecation in gardens can contaminate fruits, vegetables, and cassava or sweet potato tubers, presenting a risk for neurocysticercosis to household members. Some barriers to latrine use that promote open defecation included poor latrine design, poor access paths, poor lighting, and a low state of maintenance and hygiene. The first barrier did not guarantee privacy and ease of use while others discouraged use. These findings are consistent with findings by Kwiringira et al. (40), who reported that open defecation was practised in the slums of Kampala, Uganda and in Lodwar town, Kenya (41). Similarly, Exum et al. (42) reported that open defection in bushes or near water bodies was practised in different regions across Uganda. Failure to maintain the cleanliness of the pit latrine was found to be a significant factor contributing to the descent from the sanitation ladder back to open defecation in Uganda (40). On privacy during latrine use, Nunbogu et al. (35) reported that in Ghana, the assurance of privacy increased latrine usage by 42.5%.

Handwashing facilities were reported to be common in most households, but their use after visiting the toilet was considered by study participants to be limited in agreeance with Byamukama (43), who reported that the practise of handwashing after using the toilet was low in Uganda (52%), with only 14% using soap. A lack of handwashing and poor personal hygiene presents a risk of infections with *T. solium* cysticercosis to tapeworm carriers through the direct ingestion of eggs or to other household members through contamination of food and/or water. In a review on the availability of handwashing facilities in East African countries, using demographic health surveys, Kisaakye et al. (44) noted that Uganda had the least availability at 59.2%. The promotion of handwashing and improved personal hygiene is done by community leaders and VHTs, but may have not been achieving the desired impact. One recent intervention that has increased the awareness and the practise of handwashing is the promotion of the use of the tippy tap, which consists of a jerry can, a string, and a piece of wood in a lever system. It is operated by foot and, hence, avoids contamination of the handwashing facility (45).

The results of this study indicate that there was a positive attitude towards deworming, especially in children, but the practise is not common. There was low awareness on whether adults need to regularly deworm, with few discussants noting that they do deworm occasionally. There was no consensus on the frequency of deworming among the discussants. The WHO guidelines on preventive chemotherapy recommend annual or biannual deworming with single-dose albendazole (400 mg) or mebendazole (500 mg) in young children above 1 year, SAC, non-pregnant adolescent girls, and pregnant women after their first trimester (46). These guidelines are followed in Uganda (29). Deworming can break the *T. solium* transmission cycle by killing the adult tapeworms in humans and preventing environmental contamination. The commonly used and available deworming drugs in Uganda are Albendazole, which requires a 3-day regimen for the successful treatment of taeniasis (47, 48), and mebendazole for the treatment of *Enterobius vermicularis* (threadworms, also called pinworms), *Strongyloides stercoralis* (threadworm), *Trichuris trichiura* (whipworms), *Ascaris lumbricoides* (roundworm), *Necator americanus* (hookworm), and *Ancylostoma duodenale* (hookworm) (49). Triple dose mebendazole is also effective against taeniasis (50). It was noted that SAC was annually dewormed in school and during child's healthy days using praziquantel to control schistosomiasis. A single dose of praziquantel at 10 mg/kg is effective against *T. solium* taeniasis (51) and is the recommended drug of choice (52). The effect of the MDA campaign on the prevalence of taeniasis and incidences of *T. solium* cysticercosis in Uganda needs to be evaluated as was done in Tanzania (53).

Pig farmers had good knowledge and awareness of the importance of pig confinement in the control of diseases but keeping pigs on the free-range was still practised. There were also misconceptions and beliefs on pig confinement, with the belief that confined pigs do not grow as well as confined pigs. This may be true if the latter are poorly fed (5). Efforts to improve the adoption of pig confinement should also consider the barriers faced by farmers, including the availability of resources to construct pig pens and to buy feeds for the confined pigs and the lack of price incentives for properly raised pigs. Similar findings on barriers to pig confinement were reported in Zambia (25). An option could be to promote simple pig pen designs that could be constructed using locally available materials and alternative, more accessible feeds for pigs, such as forage and silage-based diets. These types of feeds were shown to reduce cost and have relatively good average daily gain (ADG) (54). In a study in Kenya, Levy et al. (55) concluded that small-scale traders, who could feed non-commercial feeds to pigs to attain a high ADG and could bargain with traders for better prices, were likely to benefit from semi-intensive pig farming. Low-cost, locally available, and nutritionally complete diets have also been formulated for pigs in western Kenya (56). Additionally, the traditional pig rearing sector was shown to be more sustainable than the intensive pig rearing system (57). Kabululu et al. (58) noted an improvement in pig confinement after an intervention that trained farmers through a demonstration on the construction of an improved pig pen and pig feed formulation. Results from the current study also show that pig traders demand smaller pigs (lower weight) due to the lower uptake of pig meat in rural areas and, possibly, because they lack refrigeration services and would have to sell the entire carcass in 1 or 2 days. Pig farmers in Uganda reared pigs as a form of saving, particularly to be sold for cash to cover school fees or emergencies (2). To ensure profitability for the enterprise by selling the pigs at the specified time or when a certain weight is attained, farmers may need alternative financial products to provide cash to cover emergencies and other household expenditures.

Meat inspection by government officials was reported to be irregular in the rural villages, only being conducted during holiday months when many pigs are slaughtered. Meat inspection of pigs slaughtered by the butchers across the district was reported to be irregular and ineffective due to the lack of a centralised slaughter place, lack of transport for the meat

inspectors, and political interference. Thys et al. (25) reported similar challenges to meat inspection in Zambia. The traders did not mind if the carcass was not inspected. They went ahead and sold to buyers unless an inspection stamp was demanded, as was sometimes the case for Kampala consumers. Local consumers only checked meat for physical quality attributes and not for infections like cysts. These findings were similar to Roesel et al. (3), who reported in detail the attributes consumers in Uganda consider before buying both raw and/or ready to eat pork, including cleanliness, moderate fat layer, freshness, colour, texture, and smell of the meat in order of importance.

On the other hand, traders did not report inspecting pigs for porcine cysticercosis before buying. Instead, they checked for signs of ASF and external parasites in live pigs, whilst Ouma et al. (59) reported that traders inspected pigs for *T. solium* cysticercosis through tongue palpation in the Masaka and Bukedea districts, Uganda. This contrast may be because the study focused on districts, where traders buy pigs and transport them to Kampala, while, in the current study, the traders majorly bought and slaughtered for local consumption. The motivation to inspect for ASF may be due to fear of spreading the infections that may lead to market closure and animal movement restrictions that may adversely affect their businesses. This shows that the priority for traders is the effects that diseases can inflict on their business, but not necessarily on the risk of contracting zoonotic diseases through consumption of uninspected meat. The failure of the meat inspection system in the study area may mean that pork consumers are at risk of infection with taeniasis and, consequently, neurocysticercosis. Roesel et al. (60) also reported challenges in meat inspection and law enforcement in an analysis of Wambizzi slaughterhouses in Kampala, including illegal slaughtering before meat inspectors reported to work to avoid paying the slaughtering fee.

Stomach upsets, vomiting, and diarrhoea were reported as the main effects of consuming half-cooked pork. Generally, there were low knowledge levels and awareness on the risk of getting taeniasis by eating half-cooked pork. Households practised different methods of preparing pork at home, similar to findings by Roesel et al. (3). Health education with messages on cooking/roasting coupled with enforcement of standards on the sale of ready-to-eat food may be needed to lower the risk of exposure of consumers to infective meat.

Limitations of the Study

The focus group discussants were selected from a list of farmers who had earlier participated in a cross-sectional study on risk factors for *T. solium* infections. This may have biassed the results due to the existence of prior knowledge gained from being involved in the earlier study. However, the current study focused more on aspects of control of the parasite which were missing in the earlier cross-sectional study.

CONCLUSION

Pig farmers, community leaders, and pig/pork traders had almost no knowledge of *T. solium* infections and were often confused regarding the differences existing between *T. solium* and other gastro-intestinal infections in pigs and humans. Pig confinement, pit latrine construction, coverage, maintenance, and sustained use were influenced by cultural, socio-economic, and physical/ environmental factors of the study population and area. Proper sensitisation programmes and health education interventions should target all, but with material appropriately focused to suit the stakeholder category. Reminders or nudges may be needed to ensure that any increase in knowledge translates to changes in practise. Intervention programmes should also aim to overcome challenges created by the various contextual factors operating in specific areas. Additionally, adoption of the various practises to control *T. solium* require behavioural modification by the different stakeholders, participatory design of the intervention, and integrated behavioural change frameworks should be considered in the implementation of intervention.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by ILRI Institutional Research Ethics Committee and Research and Ethics Committee at the College of Veterinary Medicine, Animal Resources and Biosecurity, Makerere University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

NN, NJ, KR, and LT: conceptualisation. NN, RW, SG, NJ, KR, and LT: methodology. NN: data collection and writing–original draft. NN, KR, and LT: analysis and data interpretation. All authors: writing–reviewing and editing. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fvets.2022.833721/full#supplementary-material

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Microbial Safety of Beef Along Beef Value Chains in the Ashaiman Municipality of Ghana

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Food from animal sources continues to be a significant food safety hazard. This study determined the microbial quality and safety of beef along beef value chains with case studies in the Ashaiman Municipality of Ghana. Raw beef samples were collected from four slaughter slabs in the Ashaiman Municipality and analyzed using standard microbiological methods to determine the quality and prevalence of specific pathogens, including *Salmonella* species, *Listeria monocytogenes* (*L. monocytogenes*), and *Brucella* species, as well as *Toxoplasma gondii* (*T. gondii*), *Cyclospora cayetanensis* (*C. cayetanensis*), and *Cryptosporidium parvum* (*C. parvum*). Data regarding food safety knowledge and practices were collected and observed from stakeholders (cattle farmers, butchers, and beef retailers). *Salmonella typhimurium* was isolated from 7.5% (6/80) of the total raw beef samples. However, *L. monocytogenes*, *Brucella* spp., *T. gondii*, *C. cayetanensis*, and *C. parvum* were not isolated in this study. The mean level of microbial contamination of beef from the slaughter slabs/abattoir [5.2 Log_{10} colony-forming unit (CFU)/g] was not significantly different ($p > 0.05$) from the mean level observed at retail points (5.4 Log_{10} CFU/g). However, the mean coliform count of 4.3 Log_{10} CFU/g recorded at retail shops exceeded the permissible limits of 10^4 CFU/g (4 Log_{10} CFU/g) required by the Ghana Standards Authority for safety of meat and carcasses. Knowledge on food safety was at average level for butchers and retailers. Unhygienic practices and poor sanitary conditions at the abattoirs and retail shops observed could be the main contributing factors to microbial contamination of raw beef. Continuous education for meat handlers on issues of food safety and monitoring of slaughter activities will reduce the rate and level of contamination of beef.

Keywords: beef, microbial safety, quality, value chain, Ghana

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INTRODUCTION

Beef is a good source of quality dietary proteins, minerals, and vitamins essential for human metabolic processes (1). Although beef provides essential nourishment for humans, it also provides a rich medium for growth of foodborne pathogens. Beef is the most frequently purchased meat product and constitutes about 52% of meat budget in Ghanaian households (2). It constitutes approximately 27.2% of imported meat products and 17% of domestic meat production (3). Although beef production in Ghana is low, the demand and patronage by consumers are high.

In the informal sector, retailing of beef is carried out in the open under ambient temperatures exposing the beef to flies, bacteria, and other contaminants (4, 5). Consumption of contaminated undercooked meat is the major route of transmission for foodborne infections. Bacterial pathogens, including *Campylobacter*, *Escherichia coli* (*E. coli*) O157:H7, *Staphylococcus aureus*, *Salmonella*, and *Enterococci*, are among the top five foodborne pathogens and globally account for 230,000 deaths each year (6). Also, protozoan parasites such as *Toxoplasma gondii* (*T. gondii*) and *Cryptosporidium parvum* (*C. parvum*) are important foodborne pathogens associated with consumption of infected raw or undercooked meat (7, 8). These bacterial and protozoan pathogens are a public health problem and adversely impact the economy in terms of loss of productivity, morbidity, and healthcare cost (9, 10).

Processing of beef along the value chain from slaughter to consumers at retail points is critical due to microbial contamination. Microorganisms may contaminate meat from the hide or intestines of the cattle or from the environmental condition in which animals are reared, slaughtered, transported, and displayed for sale in the markets (11, 12). The mode of transport of meat to the market could also contribute to contamination. It has been observed that meat is commonly transported to the markets in taxis, in head pans, on motor cycles, or on tricycles (13).

With a growing middle class, beef consumption in Ghana is increasing and with an increasing population of an expatriate community in Ghana, restaurants and other food outlets provide alternative processing options such as medium and rare cooked beef that could further increase risk of foodborne illnesses when biological hazards are present. The safety and quality of beef sold to consumers, therefore, needs to be investigated. Cattle farmers, butchers, and retailers who handle meat before it reaches the consumer could play a crucial role in the quality and safety of beef.

Again, in most developing countries such as Ghana where majority of abattoirs/slaughterhouses and meat processing units are substandard and lack modern infrastructure, poorly designed tools and equipment are used. Lack of infrastructure and standards to monitor and control the activities of cattle and beef handlers can easily lead to contamination of beef and beef products and result in food-poisoning incidents, if beef is not cooked thoroughly before consumption. Last, there is much data on the bacteriological quality of beef in Ghana; however, only a few have determined the presence of parasites in meat (14, 15). Therefore, this study aimed to investigate the bacteriological and parasitic quality of beef as well as food safety knowledge and practices of stakeholders in informal beef value chains in the Ashaiman Municipality.

MATERIALS AND METHODS

Study Area and Design

Ashaiman is the capital of the Ashaiman Municipal Assembly, located about 4 km to the North of Tema (industrial city) and about 30 km from Accra, the capital city. It covers a total land area of about 45 km^2 and falls within latitude 5°42' north and longitude 0°01' west. The municipality has one of the largest cattle markets in the country and plays a central role in the slaughter and sale of beef to other parts of the capital. The vegetation is mainly savannah grasses and shrubs, which provide food for over 27,893 livestock reared by 714 keepers. Ashaiman provides places of residence for most industry workers. However, a large number of persons are involved in cattle, chicken, goat, and sheep rearing. This study was conducted at local abattoirs and slaughter slab in four communities, including old Tulaku, Roman Down, Zenu, and Jericho in the Ashaiman Municipal Assembly. Key information survey preceding exploratory visits and interviews was done with key people at abattoirs to identify the main stakeholders of beef value chains.

Administration of Questionnaires

A total of 115 stakeholders made up of 25 cattle farmers, 22 butchers, and 68 retailers were conveniently selected and interviewed with structured questionnaire. The butchers and retailers' questionnaire captured information on demographics, acquisition of slaughter cattle, transport of beef to the retail outlets and the markets, and handling and storage of beef. Cattle farmers were interviewed with structured questionnaire to solicit information on the sources of animals, farm practices, transport distance, animal handling condition during transport, location, and training. The last section, which consisted of 6 questions, tested their knowledge on foodborne disease (FBD) and food safety. Scoring of food safety knowledge was done using scoring method described by Nee and Sani (16). Respondents were asked to choose from three options—yes, no, or do not know. The terms "correct" and "wrong" were used to indicate correct and wrong answers, respectively, by the respondents. The score ranged between 0 and 6, which was converted to 100 points and expressed as percentages. The score below 50% was defined as poor knowledge, while score above 70% was regarded as good knowledge. A checklist on items and facilities required for good hygienic practices in the handling of raw beef by butchers and retailers was used for audit.

Microbiological Analysis

Sample Collection

A total of 80 raw beef samples were collected aseptically from four (4) slaughter slabs and 12 butcher shops/retail outlet traced from the identified abattoir/slaughter slabs. Out of these, 20 samples were obtained from the four slaughter slabs, while 60 beef samples were collected from 12 different retailers located in the Ashaiman market. On each sampling day, 16 raw beef samples, each weighing 100 g, were purchased and collected aseptically into sterile polythene pouches and sealed and transported on ice to the Bacteriology Laboratory at the Noguchi Memorial Institute for Medical Research. Sample collection was repeated for 5 weeks.

Total Plate Count and Total Coliform Count

A total of 10 g of beef sample was aseptically homogenized in 90 ml phosphate-buffered saline (PBS). 1 ml of the homogenate was diluted in 9 ml PBS tubes to obtain 10^{-1} dilution factor. Serial dilutions up to 10^{-4} were prepared for the colony count. Aliquot of 1 ml of each of serial dilution was transferred to two

(2) petri dishes (4-inch diameter) labeled plate count agar (PCA) and MacConkey agar (MAC) each and molten plate count agar (PCA) and MacConkey agar (MAC) (15–20 ml) were poured on them, respectively. Plates were gently swirled to uniformly mix the sample. The plates were inverted and incubated at 37°C for 24 h. The incubated plates were examined for bacterial colonies and were counted using a colony counter.

Isolation and Identification of *Brucella* spp.

A loopful (0.1 ml) of the stock homogenate was streaked on selective *Brucella* agar, prepared aseptically by following the manufacturer's instructions using *Brucella* Medium Base (CM0169), *Brucella* Selective Supplement (SR0083), and 5.00% inactivated horse serum all from Oxoid, Basingstoke, UK. The plates were incubated at 35°C in a humidified incubator with 5 to 10% CO_2 for 72 h. After incubation, punctate colonies that were nonpigmented and nonhemolytic were regarded as presumptive. The presumptive *Brucella spp*. were streaked on nutrient agar and incubated at 37°C for 24 h. Purified colonies from the nutrient agar plates were confirmed according to procedures described by Alton et al. (17). Pure colonies of presumptive *Brucella* spp. were Gram stained and confirmed by panel of test such as oxidase production, CO_2 dependence, catalase production, and urea production.

Isolation and Identification of *Salmonella* spp.

Isolation and identification of *Salmonella* spp. were performed using procedures previously described by Addo et al. (18). 1 ml aliquots stock homogenate prepared earlier were transferred into 10 ml Rappaport–Vassiliadis Broth for enrichment. Samples in Rappaport–Vassiliadis Broth (Oxoid, CM0669) were incubated at 37°C for 24 h. 0.1 ml of the enriched samples were then streaked onto *Salmonella–Shigella* Agar (SSA) (Oxoid, CM0099) and incubated at 37°C for 24 h. Cream colonies with black centers on the SSA presumed to be *Salmonella* spp. were purified on nutrient agar and confirmed using Gram staining, analytical profile index (API) (20E, Biomérieux, France), and *Salmonella* latex agglutination.

Isolation of *Listeria monocytogenes*

A total of 10 g of raw beef was homogenized in 9 ml half Fraser Broth (Oxoid, CM0895) and incubated at 30°C for 24 h to obtain a primary enrichment broth. 0.1 ml of the primary enrichment broth was introduced in 10 ml of Fraser Broth (Oxoid, CM0895) and incubated at 37°C for 48 h (secondary enrichment broth). Both the primary and secondary enrichment broths were subcultured on *Listeria* chromogenic agar plates (Oxoid, CM1084) and incubated aerobically at 37°C for 48 h. Colonies appear blue-green with opaque halos, presumptive of *Listeria* spp. that were purified and confirmed. Catalase test was done to confirm *Listeria monocytogenes (L. monocytogenes*) by smearing pure colonies on a clean glass slide with a sterile inoculating loop. Three drops of 3% hydrogen peroxide were placed on the smear and the slide was observed for bubbles. Colonies on the blood agar plates were observed for hemolysis to confirm *L. monocytogenes*.

Detection of *Toxoplasma gondii* by PCR

Deoxyribonucleic Acid Extraction From Beef Tissue

Beef samples were minced and 25 mg of each minced tissue was used for DNA extraction following the manufacturer's instructions of a commercial DNA extraction kit (DNeasy® Blood and Tissue Kit, Qiagen, USA). All the extracted DNA samples were stored at −20°C until used.

Nested PCR Amplification

The extracted DNA was analyzed by a nested PCR (nPCR) method using the appropriate primer sets in a method employed by Prestrud et al. (19) with modification. Nested one PCR mixture contained 1X PCR buffer, 2.5 mM $MgCl_2$, 2.0 mM each of dNTPs, 0.1 μM each of forward and reverse primers, 0.5 units of Taq polymerase, and 5 μl of DNA extract. The nested one reaction condition was set and maintained at 95°C for 4 min, followed by 25 cycles of 94°C for 30 s, 55°C for 1 min, and 72°C for 1.5 min. For nested two reaction, the mixture contained 1X PCR buffer, 2.5 mM $MgCl_2$, 2.0 mM each of dNTPs, 0.3 μM each of forward and reverse primers, 0.5 units of Taq polymerase, and 1 μl of nested one amplicons. The nested 2 reaction condition was maintained at 95°C for 4 min, followed by 35 cycles of 94°C for 30 s, 60°C for 1 min, and 72°C for 1.5 min. 7 μl of each the nested PCR product was loaded into a 2% agarose gel and ran for 1 h at 80 V. The gel was viewed under UV in a transilluminator to identify any bands corresponding to *T. gondii* (225 bp for *SAG3* gene and 344 bp for *GRA6* gene).

Detection of *Cryptosporidium parvum* by ELISA

There is very little published data on elution of *Cryptosporidium* oocyst from meat products. Therefore, the procedures used in this study were adopted and modified from previous studies of Robertson and Huang (20) who eluded oocyst from cured meat. Elution of *Cryptosporidium* oocyst was performed by homogenizing 10 g of raw beef in a stomacher bag containing 90 ml normal saline and Tween-20 for 15 min. The supernatant of the homogenate was aliquoted into clean vials and stored at −80°C until analysis. Aliquoted samples were thawed to room temperature before use. *Cryptosporidium* assay was performed as described by Jafari et al. (21). Ag-ELISA Kit (Cypress Diagnostics, Belgium) was used and the manufacturer's instructions were followed. Although this method was used to detect *Cryptosporidium* oocyst in stool, it was adopted in this study due to its high sensitivity (100%) and specificity compared to acid-fast staining and co-agglutination (21–23). 50 μl of sample, positive and negative controls was added to the ELISA plate. 50 μl of enzyme conjugate reagent was added immediately and covered using adhesive plastic. The mixture was incubated for 60 min at room temperature. Following incubation, the plate was washed four times with washing buffer reagent. 100 μl of chromogen/substrate reagent was added to each well and incubated in a dark room for 15 min. Then, 50 μl stop solution was added. Reaction optical density was read at 450 nm in <15 min using absorbance-based microplate reader. A positive reaction was calculated to be double the optical density value of the negative control.

TABLE 1 | Demographic characteristics of farmers, butchers and retailers along beef value chain in Ashaiman Municipal area.

Characteristic		Farmers (*N* = 25) *n* (%)	Butchers (*N* = 22) *n* (%)	Retailers (*N* = 68) *n* (%)
Age group (years)	<20	0 (0)	0 (0)	0 (0)
	20–29	1 (4)	6 (27.2)	13 (19.1)
	30–39	7 (28)	11(50)	28 (41.2)
	40–49	14 (56)	5 (22.7)	22 (32.4)
	>50	3 (12)	0 (0)	5 (7.4)
Gender	Male	25 (100)	22 (100)	68 (100)
Education	No formal	10 (40)	10 (45.5)	27 (39.7)
	Basic school	10 (40)	9 (40.9)	32 (47.1)
	SHS/vocational	5 (20)	3 (13.6)	9 (13.2)
Religion	Christian	1 (4)	0 (0)	0 (0)
	Muslim	24 (96)	22 (100)	68 (100)
Years in business	1–5	0 (0)	5 (22)	20 (29.4)
	6–10	1(4)	9(40.9)	20 (29.4)
	11–15	4 (16)	4 (18.1)	9 (13.2)
	16–20	10 (40)	3 (13.6)	11(16.2)
	>20	10 (40)	1 (2.5)	8 (11.7)

Total Number of Participants = 115.
SHS, Senior High School.

TABLE 2 | Knowledge level score of Butchers and Retailers on Foodborne disease and food safety.

Characteristics		Butchers (*N* = 22) *n* (%)	Retailers (*N* = 68) *n* (%)
Have you heard of FBD	Yes	10 (45.5)	59 (86.8)
	No	10 (45.5)	0 (0)
	Don't know	2 (9.0)	9 (13.2)
Can you give examples of FBD	Correct	10 (45.5)	22 (32.4)
	Wrong	0 (0)	0 (0)
	Don't know	12 (54.5)	46 (67.6)
Can beef consumption cause FBD	Yes	20 (90.9)	28 (41.2)
	No	0 (0)	29 (42.6)
	Don't know	2 (9.0)	11 (16.2)
What are some of the symptoms of FBD	Correct	14 (63.6)	51 (75)
	Wrong	0 (0)	0 (0)
	Don't know	8 (36.4)	17 (25)
How can you prevent FBD	Correct	18 (81.8)	32 (47.0)
	Wrong	0 (0)	31 (45.6)
	Don't know	4 (18.2)	5 (7.4)
What do you do to ensure that the beef you sell will not cause FBD?	Correct	6 (27.3)	43 (63.2)
	Wrong	16 (72.7)	25 (36.8)
Have had formal training course on food safety?	Yes	6 (27.3)	18 (26.5)
	No	16 (72.7)	50 (73.5)
Mean knowledge score		**59.10%**	**57.60%**

Detection of *Cyclospora cayetanensis* by Modified Acid-Fast (Modified Ziehl–Neelsen) Staining

A total of 20 g of beef was homogenized in 50 ml phosphate-buffered saline Tween-20 (PBST) for 30 s. The homogenate was filtered through a 3.0-μm cellulose nitrate membrane pore after which the cellulose membrane was suspended in 10 ml PBST, vortexed for 60 s, and centrifuged for 15 min at 3,000 rpm. The pellets obtained were used to prepare a smear and stained and observed microscopically to detect *Cyclospora cayetanensis* (*C. cayetanensis*) oocyst, which appear light pink to dark purple and measures about 8 to 10 μm.

Statistical Analysis

The data obtained from the microbiological examination of the carcasses were analyzed using SPPS version 20 (IBM Incorporation). The counts were expressed in log colony

TABLE 3 | Hygienic practices of butchers/retailers in Ashaiman municipality.

Facility/Practices	Percentage of butchers/retailers (%)
Hand wash basin in service area	16.2
Sink with running water for hand washing	0
Hand wash basin in back preparation area	5.8
Availability of soap for washing hands	61.7
Towels for drying hands	11.7
Other sanitary facilities (local detergent)	29.7
Use of aprons and/or head cover	23.5
Use of screen to protect meat from flies	29.4

TABLE 4 | Transportation of beef to retail shops.

Item	Number of butchers and retailers (%) $n = 68$
Means of transport	
Taxi	44 (64.7)
Mini truck	17 (25)
Motor bike	7 (10.3)
Temperature during transport	
On ice	0 (0)
Without ice	68 (100)
Refrigerated meat van	0 (0)

forming units per gram of sample [Log_{10} colony-forming unit (CFU)/g]. One–way ANOVA was used to determine the statistical significance ($P < 0.05$) of the total plate count (TPC) and total coliform count (TCC) at the slaughter slabs and retail outlets. The presence of pathogens was presented as percentages, while results of survey and audits are given in Tables.

RESULTS

The results in **Table 1** showed the demographic characteristics of stakeholders (cattle farmers, butchers, and retailers). All the 115 interviewed were males, mostly Muslims and 40% in the 30–39 years' age range. About 40.9% had no formal education. However, vocational school was the highest level of education attained by those who had been to school. Majority (74.3%) of the stakeholders had not been trained in animal hygiene (for cattle farmers) or meat hygiene. The overall food safety knowledge score (level) was average for both the butchers (59.1%) and retailers (57.6%) (**Table 2**). However, audits result in **Table 3** showed that they do not always put the knowledge into practice. It was observed that only 16.2% of retailers had handwashing basin in service area and preparation area, 23.5% of retailers wore apron or head gear, and 29% of retailers used nets or glass as screens to protect meat from flies and dust.

All the 25 cattle farmers practiced the extensive system of raising cattle. Animals were bred by the farmer or purchased from nearby farms or other parts of the country such as Techiman, Yepi, and Tamale and neighboring countries such as Burkina Faso, Niger, and Mali. All the butchers (100%) dressed their carcasses by singeing with car tires or firewood. Cleaning, evisceration, and cutting of carcass were done on concrete slabs, but hanged for inspection. However, beef was not chilled after evisceration and after cutting prior to transportation to the markets and retail points. The most popular means of transport of meat to retail shop in this study was taxi (64.7%) (**Table 4**). Carcasses were packaged on polyethylene or cardboards in vehicles for transport. Averagely, it took butchers/retailers <1 h to transport meat to their retail shops. None (100%) of the butchers transported meat in refrigerated meat vans or on ice.

The mean TPC of beef at the slaughter slabs and retail outlets was 5.2 and 5.4 Log_{10} CFU/g, respectively, while the mean TCC of beef at the slaughter slabs and retail outlets was 3.7 and 4.3 Log_{10} CFU/g, respectively (**Table 5**). There was no significant difference between the TPC and TCC at the slaughter slabs and retail outlets ($P = 0.58$). *Salmonella typhimurium* (*S. typhimurium*) was detected in six (7.5%) of the total beef samples (**Table 5**). *L. monocytogenes*, *Brucella* spp., *T. gondii*, *C. parvum*, and *C. cayetanensis* were not detected in this study. However, other bacterial species were isolated with *E. coli* being predominant (29%) (**Table 6**).

DISCUSSION

Butchering and sale of meat at Ashaiman Municipality were mostly done by young middle-aged Muslim men within 20–49 years' age range, which is similar to findings of Frimpong et al. (13) in Kumasi. Butchering is a profession, which requires much energy and physical strength to travel several times in a week to purchase livestock from livestock market and restrain animals for slaughter (24). It is not surprising that about 40% of the study participants in this study were young males. Education and training of meat handlers about the basic concept of meat hygiene and good manufacturing practices are important in safeguarding the quality and safety of meat to consumers. This study showed that 59.1% of the participants have had some form of formal education and 25% of the participants had training on hygiene or food safety. Bhandare et al. (25) reported that abattoir workers in most developing countries are untrained and, thus, pay no attention to hygienic practices and, therefore, contribute to bacterial contamination.

Total plate count used to measure the general bacterial load to reflect the level of contamination is a useful tool in monitoring meat quality. For beef to be considered unwholesome, the TPC should exceed 7 Log_{10} CFU/g, which is the International Commission on Microbiological Specification of Food (ICMSF) (26). By the Ghana Standards Authority (GSA) criteria, the TPC should not exceed 10^6 CFU/g (6 Log CFU/g). In this study, the mean TPC at the slaughter slab/abattoir and retail shops was 5.2 and 5.4 Log_{10} CFU/g, respectively, and, thus, within the range of permissible limit of both the GSA and the ICMSF. This finding is comparable to those reported by Ahmad et al. (27) in Pakistan and Anachinaba et al. (14) in Ghana, who recorded counts ranging from 4.33 to 6.7 Log_{10} CFU/g.

TABLE 5 | Mean microbial count [in Log_{10} (CFU)/g] at slaughter slabs/abattoirs and detection of specific pathogens.

	Slaughter slab			Retail outlet		
Location	**TPC**	**TCC**	***Salmonella* Typhimurium**	**TPC**	**TCC**	***Salmonella* Typhimurium**
Tulaku	4.7[a]	4.1[a]	-	5.5	4.4	++
Zenu	5.3[b]	3.8[b]	-	5.3	4.6	+
Roman down	5.6[b]	3.3[b]	-	5.5	3.8	-
Jericho	5.2[b]	3.6[b]	+	5.3	4.5	++
Overall mean	**5.2**	**3.7**		**5.4**	**4.3**	

Means in the same column with different superscript are significantly different.
TPC, Total plate count; TCC, Total coliform count.
+, Detected in one sample; ++, detected in two samples; -, Not detected.

The microbial count enumerated from fresh raw beef indicated that the beef samples were contaminated. The possible source of contamination may include the processing area, knives, gut content, hide, meat handlers, vehicle for transporting carcass, and selling environment. It must be noted that in this study, samples were collected early in the morning, which are actually expected to be of the best quality, as the beef is freshly processed. The results also highlight the level of hygiene with respect to beef handling and storage at the retail shops. The production chain in all the slaughter slabs was poorly organized. Cleaning of carcass after singeing to cutting of meat for inspection was all done on the bare floors that were stained with blood and gut content from previous slaughter. Though the TPC of beef was within the limit considered as wholesome for consumption, the presence of pathogens such as *E. coli* and *Salmonella*, which are known to cause foodborne infections, is of public health concern (4). The mean total coliform count (TCC) recorded at the slaughter slabs and retail shops in this study was 3.7 and 4.3 Log_{10} CFU/g, lower than counts reported by Twum (5) in Ghana, which ranged from 5.29 to 5.48 Log_{10} CFU/g. In Nigeria, however, Adetunji et al. (28) reported high TCC in beef with ranges from 0 to 8.21 Log_{10} CFU/g. High TCC recorded in this study, which exceeded the permissible limits of 3 Log_{10} CFU/g required by the GSA (2013) and the ICMSF (26), suggests that the beef samples were of poor quality. The presence of coliforms in meat is an indication of poor processing activity, which was done mainly on contaminated abattoir floors and lack of separation between dirty and clean area in this study. Contamination of the beef with fecal matter could have been from the environment, flies, and other materials, including contaminated water. The 7.5% prevalence of *Salmonella* reported in this study was low compared to the 31% reported by Adzitey (29) who determined the prevalence of *Salmonella* spp. and *E. coli* in beef samples sold at Tamale Metropolis in Ghana. The low prevalence of *Salmonella* spp. recorded in this study is similar to previous studies (5, 18, 30). Isolation of *S.* typhimurium indicates a public health concern and may pose a health hazard, if beef is eaten undercooked or cross-contamination occurs during food preparation (31). The presence of *Salmonella* spp. in the meat samples is also an indication of poor hygienic practices during processing from the farm to the retail shops.

TABLE 6 | Frequency and percentage of pathogens and other bacterial species from 80 raw beef samples obtained from slaughter slabs and retail shops.

Pathogen	**Total no. (%)**	**Slaughter slab**	**Retail**
L.monocytogenes	0 (0)	0	0
Brucella spp.	0 (0)	0	0
T. gondii	0 (0)	0	0
C. parvum	0 (0)	0	0
C. cayetanensis	0 (0)	0	0
E. coli	19 (29)	9	10
S. aureus	3 (5)	1	2
K. pneumoniae	7 (11)	2	5
Streptococcus spp.	7 (11)	0	7
Citrobacter spp.	4 (6)	0	4
P. aeruginosa	3 (5)	1	2
Proteus spp.	6 (9)	1	5
Bacillus spp.	7 (11)	2	5
Enterococcus faecalis	4 (6)	0	4
Enterobacter cloacae	5 (8)	0	5
Total	**65**	**16**	**49**

Listeria monocytogenes was not isolated in this study, though it was reported to be the etiological agent for FBD outbreak in South Africa, which claimed 180 lives (32). Manifestations of listeriosis include meningitis and spontaneous abortion or stillbirth in pregnant women. The ability of *L. monocytogenes* to multiply in various foods at temperatures as low as 2 to 4°C makes the occurrence of *L. monocytogenes* in food products, of particular concern (33). The prevalence of *L. monocytogenes* and *Brucella* spp. in meat, though not found in this study, is also an indication of unhygienic meat processing (30). *T. gondii* was not detected in beef in this study, which agrees with previously published report (34). Low prevalence of 1.7 and 4% has been reported from similar studies by Rahdar et al. (8) and Hosein et al. (35) in United Kingdom (UK) and Iran, respectively. The absence of *T. gondii* in beef from this study could be that the cattle were not exposed to the infective oocyst probably due to low cat population, which are the definitive host. The findings could also confirm that cattle are able to clear the oocyst after ingestion and are, thus, resistant

to the infection (36). Neither *C. parvum* nor *C. cayetanensis* was isolated from any of the beef samples in this study, which corroborates data by Eberhard et al. (37). *C. parvum* and *C. cayetanensis* are emerging foodborne pathogens shed through the feces of chicken and dogs. However, cattle are not known to be colonized by *Cyclospora* spp. (38). Rather, irrigation water used for production of crops usually eaten raw has shown widespread presence of these parasites (39). The absence of these protozoan parasite in this study supports suggestions that cattle show lower susceptibility to these protozoan infections. Another possible explanation could be that the meat of the cattle that were sampled for this study may have not been exposed to the parasites.

Though the food safety knowledge of both the retailers and butchers was average in this study, 74.3% had not been trained on food safety and/or meat hygiene. Of those trained, 25.7% had only one training organized by the Ministry of Food and Agriculture. Some slaughter slabs/abattoirs had veterinary officers and meat inspectors at post to do antemortem and postmortem inspection of cattle and beef, respectively, before distribution to the retail shops. Although the total plate count was comparable for the farm and retail outlets, the coliform count was much higher for the samples from the retail outlets. This indicates that a transdisciplinary approach is required because merely ensuring that the quality of meat at the abattoir level is good due to the presence of trained meat inspectors and veterinarians, without ensuring that all the stakeholders in the value chain work in synergy to ensure that meat remains wholesome before consumption will not achieve desired outcomes. Value chain analysis is an essential starting point for a One Health approach to meat safety. A great example was set about a decade ago, during the avian influenza pandemic when the One Health approach was used to bring together several players from public and animal health disciplines to manage the pandemic (40). These interdisciplinary efforts mobilized value analysis as a tool to map actors, processes, and value creation to plan disease control and assess the impact of the disease and control measures (41). For beef safety, within the context of Ghana, collaborative efforts, involving veterinarians, herdsmen, butchers, public health experts, physicians and other related professionals, food and environmental regulatory authorities, district assemblies, and consumers, must work together for control and prevention of zoonotic infection transmission between the human–animal interface. There is a need to educate and train cattle farmers and beef/meat handlers to improve in sanitation and hygiene to reduce microbial contamination of beef and transmission of zoonotic pathogens to humans and the environment. Continuous surveillance by the regulatory authorities and insistence on the establishment of hazard analysis and critical control points (HACCPs) by meat retail outlets would ensure that the consumer is protected from unwholesome meat. Of course, while laws ensure compliance, a participatory approach will be critical to the success of any transdisciplinary approach. Hence, all the identified stakeholders in the beef value chain must be given the opportunity to participate in the process, so that there is a sense of ownership that will lead to sustainably any efforts at improving beef quality and safety.

CONCLUSION

Food safety in the beef production chain requires training and collaboration with all the partners and veterinarians play an important role. This study revealed that beef sold in the municipality is contaminated with pathogens such as *S. typhimurium*, *E. coli*, and *Staphylococcus aureus* (*S. aureus*). Though the prevalence of *S. typhimurium* in this study was lower (7.5%) than that described in previous studies from Ghana, its presence together with other pathogens isolated is a public health concern. *L. monocytogenes* and *Brucella* spp. were not isolated in any of the beef samples. The absence of these pathogens is good, but consumers of beef need to be aware that meat should be cooked thoroughly at temperatures above 75°C in order to kill all pathogens, which may be present in beef. This study makes a case for using a One Health approach to achieve food safety.

DATA AVAILABILITY STATEMENT

The data analyzed in this study is subject to licenses/restrictions. Requests to access these datasets should be directed to vyadjei@gmail.com.

AUTHOR CONTRIBUTIONS

VA, KA, AP-HK, and KT-D designed the study. VA wrote the protocol and first draft, did the sample collection, and performed the bacterial isolation and identification. IA provided technical support for parasite identification in the Parasitology Department of NMIMR. GM and VA performed the data analysis. GM, VA, KA, IA, AP-HK, and KT-D reviewed the manuscript. All authors have read and approved the final version of the manuscript.

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"How Are My Age and Cows Related?" Cognitive Interviewing as a Tool to Pretest Survey Questions in Two Limited Resource Settings

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Antimicrobial resistance is a complex topic requiring interdisciplinary solutions embedded in One Health thinking. Currently, many surveys are underway in low- and middle-income countries to study how antimicrobial use in the livestock sector is driving resistance. In a survey, the respondents must understand and answer the questions correctly to produce accurate and valuable results. Pretesting survey questions is therefore important but sometimes not performed due to limited time and resources. Cognitive interviewing is a pretesting method to give insights into the respondent's way of interpreting and mentally processing the survey questions to identify problems and finding ways to improve the questions. It has previously been suggested that cognitive interviews may be difficult to use in some cultural settings. This study aimed to use cognitive interviews in a respondent-adjusted way to study how survey questions related to antimicrobial use are understood and answered by 12 small-scale farmers in Kenya and Uganda. The results show that even a small number of interviews and using interviewers with limited knowledge of cognitive interviewing can identify many problems in survey questions and the survey tool. Cognitive interviews may provide a feasible and affordable way of pretesting questionnaires in situations where time and resources are limited, for example, during a disease outbreak.

Keywords: cross-cultural, cognitive interview methods, livestock, One Health, questionnaire, survey, antimicrobial resistance, behavior

INTRODUCTION

One Health is an integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals, and ecosystems (1). In contrast to Veterinary Public Health at the interface between animals and humans with human health as the key outcome, One Health acknowledges that human, animal, and environmental health are closely interlinked and connected and need to be looked at as a system. As such the environment does not only impact disease spread (i.e., climate change shifting the distribution

of vector-borne diseases) but is also equally affected by the increased population growth and consequently, the increased demand for animal protein (i.e., greenhouse gas emissions, pollution). The increase in humans and animals adds pressure on resources and means more treatment of infectious diseases with antimicrobials including antibacterials, antifungals, antiparasitics, and antivirals. These substances are often used across species and can end up in the environment.

Antimicrobial resistance (AMR) is one of the major global health threats, projecting that as many as 10 million people could die annually from AMR by 2050 (2). A more recent systematic review estimated 4.95 million deaths associated with bacterial AMR only in 2019, including 1.27 million deaths directly attributable to bacterial AMR (3). These estimates indicate that bacterial AMR is a health problem with a magnitude similar to major diseases such as HIV and malaria, with the highest regional burden in the Sub-Saharan African region (3). The livestock sector is often held responsible for disproportionate use of antimicrobials to either promote growth or mask hygiene and biosecurity issues on farms. However, one of the major gaps in controlling AMR in Sub-Saharan Africa is the lack of data and knowledge on behavioral drivers for the use of antimicrobials and how they can be addressed. This data gap prompted the development of the AMUSE tool, a survey tool to assess antimicrobial use in livestock systems in low- and middle-income countries.

The common way of pretesting questionnaires in biomedical surveys at the International Livestock Research Institute (ILRI), for instance, risk factor analyses which relate a lot to practices that lead to exposure to zoonotic diseases, is as follows: First, the researcher goes through the questionnaire with peers to speak out the questions. Many peers in the field of research for development in Africa are livestock keepers or crop farmers and therefore, represent a knowledgeable test group. Speaking the question out loud often leads to rephrasing questions to avoid nested sentences, leading questions, or several questions asked in one. Following that, the questionnaire is administered to some sample farmers who represent the target group. Mostly, the target audience is rural small-holder farmers with primary education and multiple agricultural activities to provide for their families' livelihoods and food security. In many African countries, there is one official administrative language, such as English, French, Kiswahili, or Portuguese, and the questionnaire is written and administered in that predominating administrative language assuming that the respondent has enough knowledge to understand and respond to the questions. If that is not the case, the interviewers, who are usually nationals of the country where the survey is implemented, translate the questionnaire on the spot (or on the fly), or the respondent understands the questionnaire in the official language but responds in their local dialect. During this pretesting step, the researcher usually monitors how much time it takes to administer the questionnaire and notes if the respondents ask questions about how to answer specific questions. This process however gives little insights into how questions are understood and answered by the respondents. We cannot be sure if, for example, the respondent has the same understanding of an issue as was intended when developing the question.

In a survey, the respondents must understand and answer the questions correctly to produce accurate and valuable results. Cognitive psychology provides a theoretical framework to understand how respondents answer survey questions (4, 5). The four steps needed to answer a question are (a) comprehension of the questions, (b) retrieval of the information asked for, (c) judgment of the information, and (d) response. Problems in comprehension are, for example, if the question is understood in a different way than intended or if different respondents understand the question in different ways. Problems in retrieval occur when the respondent cannot remember or does not have access to the information asked about. Problems related to judgment have to do with the processing of the information to formulate an answer, for example, deciding if a recalled event should be included in the answer or combining different experiences to an overall attitude. Finally, the respondents must respond to the question by choosing between the response options provided or by formulating their response to an open-ended question. Failure to perform any of those steps can result in incorrect or unprecise answers.

Cognitive interviewing is a questionnaire pretesting method to give insights into the respondent's way of interpreting and mentally processing the survey questions (6–8) in national surveys as well as cross-cultural settings (9). Understanding what causes problems for respondents often gives insights into how to improve the questions (7). Cognitive interviewing is a qualitative method that has developed over the last 30 years. One of the most commonly used techniques to perform cognitive interviews is think-aloud interviewing in which the respondent is asked to speak out everything (s)he is thinking when answering the questions. This method is often combined with asking specific questions (probes) to give deeper insights into the thought process. The strength of cognitive interviewing is the insight into the response process with the aim of both improving the quality of data but also improving the survey tool from the perspective of the respondent (10). Limitations are, for example, that it is a qualitative method that will not give numbers or show the extent of the problems identified, it relies on the participants' ability to verbally articulate their thoughts and the results are often based on a small number of interviews (7).

It has previously been suggested that cognitive interviews work differently in different cross-cultural settings (11–15). For example, it may be difficult for respondents in Asian settings to express critical views of the questions, especially if the survey is perceived as a representation of an authority (14, 16). Pan (14) identifies several challenges of performing cognitive interviews in Chinese: The first is explaining that the purpose of the interview is not to test the participant but to test the questionnaire; the second is that the participant is trying to find "the right" answer to satisfy the interviewer; and the third is related to problems with the respondent understanding and answering probes (especially paraphrasing types). Other authors have reported similar results when performing cognitive interviews in the Korean language, in Japan, and among Chinese immigrants in the United States (17–19).

In Africa, there are examples from Ethiopia, Kenya, Malawi, Zimbabwe, and Zambia of conducting cognitive interviews with

different success rates (20–22). Several authors have reported respondents being anxious and uneasy during interviews in populations not used to taking part in surveys (15, 20, 23). In some cases, the researchers asked several probes after each survey question, and this made the respondents feel uncomfortable (20). However, after the interviewers abandoned the highly structured probing and allowed for more flexibility in the interview, the situation improved.

Another challenge of carrying out cross-cultural surveys or surveys in countries with many local languages is that in many situations, it is not possible to do full-scale multilingual translations. In practice, according to our experience, many studies use on-the-fly translations by local interviewers. Such translations require the questions to be clear and specific to make the task easier for the interviewer and reduce the risk of questions not being accurately and consistently asked, leading to bias in the answers (24). Using a questionnaire in cross-cultural settings also restricts the possibilities for extensive training of the interviewers in cognitive interviewing to be able to pretest the questions in many different languages.

It is a good scientific practice to pretest questionnaires and survey tools (25–27). However, it may not be possible to use state-of-the-art techniques due to the number of different cultural settings or languages and the lack of institutional capacity or time. In cases of natural disasters or disease outbreaks, there may be, for example, very limited opportunities and time for pretesting. However, also in studies where pretesting should be possible, it is often not prioritized. In a recent audit of survey pretesting in a sample of medical education journals, <7% described pretesting of survey items before use (28). In the same study, the authors conclude that the low frequency of pretesting was the same when comparing articles published in low- and high-impact factor journals. Considering the meticulous methods described in the literature, researchers may be discouraged from doing even simple pretesting.

In the context of AMR, which is a very complex technical subject area on its own, there is a need for pretesting methods that can be used with limited resources, including time, but still, allow one to detect problems in the questionnaire design. While the approach of cognitive interviews for pretesting is not novel, it is not commonly used in low-resource settings. In this study, we show how cognitive interviews can be used feasibly and affordably in situations where there is a need to, for example, do so quickly during a disease outbreak or when the pretests must be performed in several local languages.

MATERIALS AND METHODS

The Survey Tool Used for Pretesting

The AMUSE tool was developed in 2018 by a team from the livestock health flagship of the CGIAR Research Program on Livestock to investigate the key linkages in the AMR conceptual framework (29). Following a review of different survey tools used in the past, the team drafted the first version of the AMUSE questionnaire, which was launched in several countries in Africa and Asia (30) including Ethiopia (31), Uganda (32, 33), and Vietnam (34). As a next step, the questionnaire was developed into a generic tool to assess antimicrobial use in animal production (including livestock, poultry, and fish) to enable comparison between different countries and settings (**Supplementary Material**). The original version of the questionnaire consisted of 76 questions, sometimes with several items per question. There was no ambition to suggest improvements for the questions beforehand in this study since the task was using the cognitive interview approach to pretest the existing version. The cognitive interviews were done on the entire questionnaire to pretest all questions as well as question order and length.

Setting and Sample

Interviews were conducted in March 2019 in Murang'a county (Kandara subcounty) and Kiambu county (Kikuyu subcounty) in Kenya ($n = 7$), and in Mukono district (Mukono subcounty) and Nakaseke district (Kapeka subcounty) in Uganda ($n = 5$) by two interviewers, one a Kenyan and the other a Ugandan. Both interviewers were men, in their early thirties, and had worked in the field of livestock research for approximately 10 years including interviewing experience. Four notetakers (two in each country) were responsible for taking notes during the interviews. An experienced survey researcher was present during the fieldwork who did not interfere in the interview but made observations on the process and perceived non-verbal signs. After each interview, the group had a debriefing about the experiences from the interview and the interviewers were advised for the upcoming interviews.

The participants were selected purposively with the help of local contact persons. We asked for livestock farmers of different socio-economic backgrounds, livestock species maintained, and a balance between male and female farmers. We interviewed seven men and five women aged between 28 and 68 years and with a variation in urban and rural settings. The participants were small-scale farmers with typically 3–15 animals (cows, pigs, goats, or chickens). The interviews were conducted in Kiswahili in Kenya and Luganda in Uganda, except for one in English.

The interviewers and notetakers were given a half-day introduction to the cognitive process of answering survey questions and the use of cognitive interviews to get insights into the response process of a respondent. They were trained to introduce the task of "think-aloud" to respondents, what to note during the interview, and how to probe. A few predefined probes were used in all interviews and the interviewers were encouraged to use spontaneous probes according to their judgment. The two notetakers were trained to make notes on a standardized protocol, especially noting things that would not be caught on the recordings such as showing signs of being uncomfortable or getting tired. They were supposed to be silent observers but were allowed to add probes at the end of the interview if they made an observation that suggested that a question was misunderstood or if there was something else that the interviewer did not follow up on.

It was important for the interviewer to contribute to a respondent-adjusted approach by creating a friendly, relaxed atmosphere to make the participant feel comfortable because we wanted to understand how the respondent processes the question instead of solely focusing on the response to the survey question. This was done by some small talk when looking for a good spot

TABLE 1 | Categories of problems with the questions and description.

Category of problems	Description
Cognitive problems	
Comprehension	Problems in understanding the question or specific concepts
Retrieval	Problems in retrieving or recalling the information asked for
Judgement	Problems in estimating, calculating or making a judgement
Response	Problems in formulating or selecting an appropriate answer
Other problems	
Unclear relevance	Respondent does not understand the reason for the question
Inappropriate assumptions	Question assumes things that are not true for the respondent
Sensitive question	Respondent perceives the question as sensitive or intruding
Interviewer rephrasing question	Interviewers use different or incorrect phrasing of question
Interviewer mistake	Interviewers' mistakes, for example, in filter questions or reporting of answers

to do the interview and avoiding any types of authoritarian or bureaucratic approaches. The time limit of the interviews was set at 1 h and they lasted between 45 and 60 min. To thank the participants, in-kind incentives of 500 g of sugar and a packet of tea were given in Uganda, and 500 g of sugar and 2 kg of maize flour were given in Kenya, but not announced in advance. None of the interviewed farmers lived close to each other or knew each other to ensure that information about the token of appreciation was not spread to subsequent respondents and thereby avoiding the risk of the incentive influencing their choice to participate. The interviews were done during 1 week in each country, and all interviews were audio-recorded after having obtained the participants' consent.

Data Management and Coding

One of the two notetakers did a simultaneous translation into English and transcription of the audio-recorded interviews as soon as possible after the interview (usually the same or the next day). The transcriptions were then re-organized to gather all findings of a specific question. All findings were then categorized into (1) cognitive problems (problems in comprehension, retrieval, judgment, or response) or (2) other problems (unclear relevance, inappropriate assumptions, sensitive questions, problems in translation, phrasing, or other interviewer mistakes) (**Table 1**). The findings of each question were then analyzed and suggestions were made on how to improve the questionnaire. In the Results section, citations from interviewers (I) and participants (P) are given. They are sometimes shortened but not altered in other ways.

RESULTS

The complete original AMUSE tool with 76 questions was administered to 12 respondents using a cognitive interview approach. The findings were consolidated for all questions in a comprehensive working report that was handed over to the team working on the development of the AMUSE questionnaire who then developed a revised version of the original questionnaire. The cognitive interview team did not take part in the revision, which resulted in a new version of the questionnaire (30). The working report can be shared upon request.

The following sections summarize how the method worked in practice and gives specific examples of questions from the original questionnaire and how cognitive interviewing helped identify problems in the design of them as well as suggested revisions based on the analysis.

Experiences of How the Cognitive Interview Practice Worked From the Respondents' Perspective

In general, the use of a respondent-adjusted interview style worked well. Respondents were relaxed and most of them engaged in the think-aloud process. Some respondents were quieter and were asked more probes to compensate for this. In some cases, the interviewer would just say "mm" or "aha" and keep looking at the respondent as if expecting more comments and giving enough time for the respondent to continue before moving to the next question. This was a successful way to give the respondents time to reflect and encourage them to talk more without the pressure of probes. Signs of the respondents feeling comfortable and interested were that they, for example, questioned the relevance of questions and commented on questions that seemed redundant or the length of the questionnaire. No negative reactions of respondents such as feeling uneasy, uncomfortable, or distressed were observed.

Examples of Findings and Suggested Revisions for Specific Questions

Example 1: Do you have hired workers on your farm? Yes / No, family members only

> I: Do you hire workers on your farm to look after your animals? P: I had them in the past, but these days I don't. I do the work myself. Maybe occasionally I can pay a little money to a casual laborer to help me do some work.

The cognitive interviews revealed two important things. In several cases, the interviewer spontaneously added information that the question concerns work with the animals. This need to be specified in the question if the answer should not include workers that only help with, for example, crops. The interviews also showed problems with comprehension of the concept "hired workers." As shown in example 1 the participant did not include casual laborers. The question needs to be rephrased to clarify the intention to include all kinds of hired workers, even just temporary paid help. A new suggestion could be: Do you have employees or casual workers that are involved in working with the animals?

Example 2: Was the disease diagnosed other than by yourself? Yes / No. If yes, by whom? Traditional healer / Community animal health worker / Private veterinarian (Diploma, BVM), Official (governmental) veterinarian / Other (This question is

a follow-up question after a question about what diseases the different species had in the last 2 weeks).

> P1: Which disease? I: The diseases that the pigs and poultry are facing now. P1: In pigs. I called a vet.
>
> P2: A private vet. I: So this vet, do you know his level of education or his qualifications? P2: I measure qualification from curing my animal [laughing] as long as he treats it and it gets cured and even a second time he cures them why don't I call him a vet.

The structure of the questionnaire was to ask each question for all the different animal species on the farm. The interviews showed that it was burdensome for both interviewers and respondents to go through each question for each animal species. For example, for the interviewer to ensure if the answers covered all species or not. In example 2, P1 had experienced diseases in the pigs and poultry and when the follow-up question was asked on who diagnosed the disease (s)he is not sure which disease the question concerns. This complicated structure often required the interviewer to ask extra questions to ensure all species had been covered and, in some cases, caused missing or incorrect registrations of answers. To avoid those problems, a suggestion from the results of the interviews was to organize the questions into one section for each species. In that way, it would be easier for the farmer to focus only on one species at a time and answer all questions about the diseases experienced and the drug used, for example, in the pigs.

Some questions were asked about things that the farmers had limited knowledge of, and therefore could not give an accurate response. This is usually referred to as retrieval problem when the respondent has no knowledge or cannot remember the information asked for. One such example is when asking about qualifications of the veterinarian in example 2. On another question that asked about the qualifications of veterinarians, one farmer explained the difficulties like this: *P: No one will present their certificate or anything like that. We hear about the doctors from word of mouth, like the one I have engaged with the longest was introduced to me by a friend*. Similar problems occurred in a question about what drugs had been used on their animals by veterinarians. Two of the participants described this as impossible for them to know since veterinarians sometimes concealed the drugs. *I: Can you remember any name of a drug you or your vet has used? P1: No, the vet never allows me to have a look. P2: I never got to see them from the vet, they are always in a bag*.

Example 3: Which period of the year do you regularly sell pigs? Throughout the year / Seasonal (possibilities to mark specific months from January to December)

> P1: I sell after six months. Sometimes I sell the piglets at 2 months old when I need money urgently. But I would prefer to sell when 1 year old. This way I can profit more. In case of urgent money, I sell at 2 months.
>
> P2: I sell whenever there is demand, if a buyer comes, I will sell the pigs no matter the season. I cannot refuse to take money.

The questions about what periods over the year the farmer sells milk, eggs, or animals caused problems for several farmers since considerations for selling include, for example, opportunities to sell, shortage of feed, or the need for money. The question incorrectly assumes that selling is predominantly done during certain periods of the year which causes problems for the farmer to select an appropriate response option. More suitable response options could be: Throughout the year / Certain months or periods / Occasionally.

Example 4: Livestock contributes to: To half or more of the household's income / To less than half of the household's income / Does not contribute to the household income.

> I1: What amount of the income does it contribute to?
>
> I2: To what extent does farming contribute to your total income?
>
> I3: How much do poultry and cattle contribute to your income?
>
> I4: The general income – what's the percentage that is contributed from the livestock?

This example shows that when the information asked for is not stated as a question, the interviewer needs to transform the text into a question. This was the case in several questions in the questionnaire and caused an additional burden for the interviewer to rephrase the text into a question and simultaneously make the translation. It caused unnecessary variations of phrasings of the question in each interview. In the example, the question was phrased as *What amount? To what extent? How much?* and *What percentage?* There is also a variation if referring to income from farming or specifically from the animals and none includes information that the question concerns the income for the whole household. A better question could be: What part of your household's income comes from the animals?

Example 5: Age of the respondent (years).

> I: How old are you? P: 41. Maybe it will depend on one's understanding, because when you approached me you talked about cows, so one can wonder how my age and cows are related. I: So, one can wonder how the question is related to animals. P: Yes.

Again, the text needed to be rephrased into a question by the interviewer. One of the participants also asks about the relevance of a question in relation to the purpose of the survey. This version of the questionnaire started with eight questions about the characteristics of the respondent, the household, and the farm. For example, the question in Example 4 about the household income was asked before any questions about what animals the farm had. It was therefore suggested from the interviews to start asking about the animals as this was specified as the purpose of the interview and would probably be expected, and relevant questions from the respondents' perspective and the demographic questions were moved to the end of the questionnaire.

Example 6: What do antibiotics do? (multiple answers possible) Cure sick animals / Prevent animals from becoming sick / Cure sick animals and prevent animals from becoming sick / Fattening

I1: So, what of antibiotics what do you think they do? P: they kill sickness.

I2: And what are antibiotics for according to you? P: according to how I understand them, they are for curing.

The question "What do antibiotics do?" led both interviewers to rephrase it a bit softer than the question stated in the questionnaire. The interviews also showed a missing response option. It was not possible to register "Don't know" even if a respondent specifically expressed, *I really don't know*.

For most check-all-that-apply questions in the questionnaire (like the one in Example 6 allowing multiple answers), it was not specified if the interviewer should read all options or just tick the ones the respondents mentioned spontaneously. This sometimes led to missed information, for example, when all species of livestock were not read out, chicken kept on a farm with mainly pigs were not mentioned. In other cases, the information would differ substantially depending on if the interviewer read all alternatives that the participant could choose from, or not. In Example 6, in some cases, the interviewer asked specifically about the options not mentioned which resulted in more registrations compared to answers based only on what the participant spontaneously mentioned.

Because it is a tick-all-that apply question, there should be no need for the response option "cure sick animals and prevent animals from becoming sick." Suggestion for the revision was to re-formulate the question to make it clear that the respondents should answer what they believe. A further suggestion was to make it clear that each option should be read out. For example, saying What do you think antibiotics can be used for? Followed by three sub-questions; Do you think antibiotics can be used to cure sick animals? Yes / No / Don't know and likewise for "to prevent animals from getting sick" and "to make animals grow faster." This will give information about the farmers' understanding of each of the uses and which uses they think they know about, and which they do not know.

Example 7: Herd flock size (number of animals for each species). Pigs: Sows / Boars / Growers or fatteners / Piglets (<3 months).

P: In total I have 10 pigs, with piglets inclusive. I: How many sows do you have? P: Six. 1 adult and 5 piglets. I: How many young pigs do have? P: 5 female ones. I: How many under the age of 3 months? P: Three, no, five I: Five? P: Yes.

The cognitive process becomes complicated when starting to divide all animals into gender and then divide into adults and young ones and then finally add the young male and female together. There are 10 pigs in total, but only 1 sow and 5 piglets are registered (probably because of the confusion about the number of female pigs where the farmer counts also the female piglets). Based on the results from the interviews, the suggestion is to make the question easier by first asking only about adults above a certain age. Out of those adult animals you just mentioned, how many are sows. Then continue to ask about the younger animals. This would probably make it easier for the participant to get it right from the start and less need for extensive probing for the interviewer.

Example 8: Do you consume milk from animals that were just treated with antimicrobials? (Similar questions for eggs and meat).

I: So, the cow that has been on antibiotics can you take its milk? P: For the first 3 days we give it out. I have a friend who has pigs, so I give the milk to the pigs. I: So, what of the poultry can you eat its eggs when it has been on antibiotics? P: Yes, we do sell them. I: Okay but even you at home do you eat it? P: But for us we don't normally eat eggs I: Let's take an example that you eat eggs, can you eat them? P: Yes, we can because even people take antibiotics but for the cow the medicine that treats fever in cows - people don't use it. So that's the difference.

Although this is a sensitive question some farmers were open about consuming and selling products. But on the other hand, some farmers said they would always dispose of the milk or eggs but when asked about how honest other farmers would be they thought many would not be honest.

I1: Do you think most farmers will give honest answers to this question? P: Most people will lie.

I2: Will they [other farmers] be honest when asked about this? P: The dairy farmers will lie, because pouring out milk is hard for many. You know why I say this is since someone might have a lot of milk on their farm and they will not be willing to pour out a significant amount of this.

These examples show that the cognitive interviews identified various problems from almost all categories listed in **Table 1**.

Example of How the Cognitive Interview Practice Worked With Interviewers With No Former Experience in Cognitive Interviews

Interviewers who are not familiar with performing cognitive interviews may encounter problems especially when it comes to when and how to probe. In some cases, the analysis showed unclear statements by the farmer that an experienced cognitive interviewer may have identified and followed up with a probe. There were also situations when the interviewer did not probe neutrally.

I: So, do you have some hired employees at the farm? P: Yes, we have and even have people from outside. I: And those people from outside are they friends? R: They are casual laborers I: But they are also hired? P: Yes, they are.

A more optimal probe after the participant's first answer could be "Can you tell me more about that?" or "Can you tell me more about what you mean by people from outside?" instead of suggesting them to be friends. This shows the importance of transcribing the interviews to be able to take the phrasing of probes into account in the analysis. In the above example, the probe is not optimal but still results in valid information. The respondents describe his/her definition of "people outside" and were not affected by the interviewer's suggestion that they were friends.

DISCUSSION

We wanted to explore the usefulness of cognitive interviewing in a situation that would probably be the case in multinational surveys involving many different settings and local languages and with limited funds for translations "by the book" and for pretesting. Pretesting by carrying out a few cognitive interviews can help identify problems that can later be avoided in real survey interviews. The results from the interviews led to a major revision of the questionnaire (30).

The interviewers in this study were experienced in conducting interviews but had no previous experience with cognitive interviewing. The interviewers need to understand that their role in cognitive interviews is different from that in a study where the task is only to register answers. In a cognitive interview, the interviewer needs to be sociable, communicative, and able to identify what issues to follow up by probes and to know when to proceed depending on the respondent's mood and reactions. Mohorko and Hiebec (35) have discussed the importance of interviewer involvement for the successful results of cognitive interviews.

Other studies have found that certain types of probes may be difficult for respondents, especially paraphrasing probes or too many probes (14, 20). A possible explanation given by Pan (14) is that Chinese students are taught to memorize and repeat texts and not express opinions or challenge authorities. Martin et al. (20), with experience in Kenya and Ethiopia, suggest difficulties due to participants being unaccustomed to thinking aloud and answering cognitive probes. On the contrary, Vreeman et al. (23) reported that respondents in Kenya have an easier time answering probes than "thinking aloud" and suggest it may be due to a cultural communication style that values listening higher than verbalizing thoughts. Participants in that study said that they felt disempowered and blamed themselves for not being able to answer due to lack of education. In the second round of cognitive interviews, the instructions were clarified, the number of probes reduced, and difficult probes such as paraphrasing were avoided. Another study shows that the think-aloud method does not work in some cultural settings such as India, but the cognitive interviews still revealed extensive question failures (15). In this study, we balanced the type and number of probes to make the respondent feel comfortable and competent; we found that this flexible approach to the interviews resulted in valuable information. For example, just saying "mm" or "eeh" and waiting for the respondent to keep talking made it less necessary to ask specific probes and thereby avoiding questions that could be perceived more like an interrogation for an insecure respondent.

The relaxed atmosphere that the interviewers managed to establish was probably a crucial factor in the successful use of cognitive interviews in this study. In earlier studies on cognitive interviews, distress among respondents was observed and the authors noted the importance of cultural adaptation (19, 20). We find, however, little information on how to train interviewers to build trust and create a friendly situation in cognitive interviews as is done, for example, in participatory epidemiology (36). In this study, for example, interviewers made small talk with the respondents while looking for a good spot in the shade to conduct the interviews. The interviewers were also asked to wear clothes that are not too formal, and avoid such as a lab coat or suits and ties that could imply a visit by an authority figure. Based on the authors' experiences from working on different projects in the area, many rural smallholder farmers have little exposure to formal surveys, also they are humble, often have little trust in governments, and may feel audited if a formally dressed investigator asks questions. For instance, pastoralists may be reluctant to respond to questions about their accurate herd size out of fear of taxation. Another probably crucial factor was the introduction given to farmers that the questionnaire had been made for use in another country and the purpose of this interview was to find out if the questions were possible to use in Kenya and Uganda or if the questions needed to be adjusted for the new setting and population. The participants were also asked for advice on what they would change about the questionnaire or specific questions. This probably made the participants feel good in a way they could contribute to making the questionnaire better as well as less prone to perceive the situation as a test or investigation. Suggestions to improve the questionnaire included making it shorter, avoiding redundant questions and "elaborating on the questions so that one can easily understand." These suggestions show that the participants felt comfortable raising points of criticism.

The cognitive interviews in this study gave many and varied results that helped revise the questions. This is particularly important, as the questions addressed different concepts, such as knowledge, behavior, and questions on context and disease problems. We believe that the method used in this study identified the most significant and common problems and provided valuable information to revise the questions before further use. Cognitive interviews are often used in combination with other pretesting methods such as focus groups, usability testing, and pilot tests. The strength of cognitive interviews is that they have the potential to reveal problems such as misunderstanding of questions that would, for example, in a pilot test seem to be a valid answer. On the other hand, a pilot test based on a larger number of respondents can reveal, for example, problems with ceiling effects and item nonresponse (7).

One limitation in this study was that the interviewers did not always succeed in identifying problems that would have been clarified by one or two probes. They would also sometimes ask probes in a leading instead of a neutral way as shown in Section 3.3 of the Results. However, also when the probes were not optimal, the results still provided valuable knowledge.

The questionnaire was also too long to provide a deep understanding of the cognitive process by using probes for each question. It was, however, still possible to identify several problems that needed clarification in the revised version of the questionnaire. Furthermore, the interview recordings were translated and transcribed simultaneously. An alternative procedure could have been to transcribe it first in the local language and then translate it into English. That would, however, take more time and could lead to more errors when the information is going through two separate steps of transcription and translation. To conduct cognitive interviews with limited resources, we think the simplified process with simultaneous translation and transcription worked satisfactorily.

Another limitation was that we only conducted a single round of 12 cognitive interviews. What is an appropriate number of interviews depends on issues such as complexity of the questions and the diversity of the target population (7). We had aimed for 5–10 interviews in each country since it is often advised to do 5–15 interviews per interviewing round (8). All interviews were done with smallholders in low- and middle-income settings. The purposive sample led to both male and female respondents and different livestock species being kept to ensure a variety of perspectives. The findings were summarized in a working report which was handed over to the team working on the development of the AMUSE questionnaire. It would have been valuable to make another round of interviews after the revision to pretest also the revised version of the questions as well as continuous testing in other languages and cultural settings.

Because we wanted to evaluate how the interview method worked, we used two notetakers that would also observe the atmosphere during the interview and note any signs of the respondents feeling uncomfortable or irritated. In an ordinary pretest we believe one notetaker would be enough. It was however very valuable that the notetaker who participated in the interview also made the transcription. In this study, a survey researcher with long experience in performing cognitive interviews was present in the field to follow the process. We believe that it is important to give interviewers with limited experience in cognitive interviewing possibilities to discuss any problems they encounter and get feedback on the results of the first interview before proceeding. This can, however, probably be done virtually. Despite the differences in cultural background and previous experience in cognitive interviews, all participants in the research team agreed that the method was successful in finding various problems with the questions and perceived that the respondents felt comfortable and at ease during the interviews. Scott et al. (15) discussed difficulties in interviewing respondents one-on-one without family members present. This was a minor problem in this study as the questions were not sensitive to answer in the presence of family members. However, there were local government veterinarians who were eager to participate in some of the interviews. This could distort the results when questions relate to information that farmers would not want to reveal to their local veterinarian. It is important to give interviewers clear instructions on how to handle such situations and provide them with responses to explain why external persons cannot participate.

CONCLUSIONS

The results show that using cognitive interviewing, even with a small number of interviews and using interviewers with limited knowledge of cognitive interviewing, can identify many problems in survey questions and the survey tool. Cognitive interviews may provide a feasible and affordable way of pretesting questionnaires in situations where time and resources are limited, for example, during a disease outbreak.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

MW conceived the study, design and implementation of interviews, and wrote the manuscript. KR conceived the study, design and implementation of questionnaires, and revised the manuscript. NN and DN conducted the fieldwork. BW co-developed the AMUSE tool and revised it following this study. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fvets.2022.833748/full#supplementary-material

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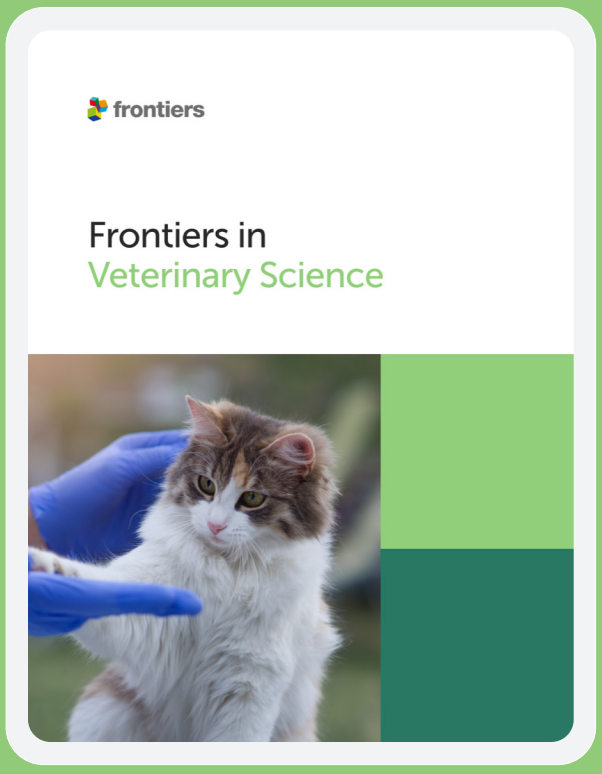

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