Preventive Veterinary Medicine xxx (xxxx) xxx

Contents lists available at ScienceDirect

Preventive Veterinary Medicine

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

Measurement and sampling error in mixed-methods research for the control of *Peste des Petits Ruminants* in the Karamoja subregion of Northeastern Uganda: A cautionary tale

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ARTICLE INFO

Keywords:
Participatory epidemiology
Questionnaire household survey
Pastoralism
Peste des petits ruminants
Community animal health workers

ABSTRACT

A team of interdisciplinary researchers undertook a mixed methods, participatory epidemiology (PE) based study as part of a pilot project for localized control of *Peste des petits ruminants* (PPR), a small ruminant disease of high socio-economic impact. Mixed methods research combines qualitative and quantitative methods, allowing iterative comparison of results to arrive at a more comprehensive and informed outcome. In this study, the use of PE and a household survey (HHS) resulted in contradictory results. However, the mixed methods approach also facilitated the detection and the explanation of bias in the HHS, which may have gone undetected and unexplored had only one method been used. Results show that logistical constraints leading to a failure to apply key aspects of the sampling strategy led to problematic gender/ethnic composition of the HHS sample population. Additionally, while PE findings on local disease and terminology were integrated during HHS development and training, there is apparent measurement error related to enumerator bias in HHS results, possibly due to insufficient respondent understanding or a lack of analytic clarity. The extensive nature of the PE, surveillance methodologies used in the initial site assessment, and formative research for the HHS allowed for a critical analysis and interpretation of HHS results as well as reflection on the research process. The findings of this paper underscore the (1) flexibility and utility of participatory methods, (2) the importance of mixed methods research in designing health interventions, and (3) the necessity of tight integration of study design with team planning for implementation of research in environments such as Karamoja, Uganda. If all three are to be achieved not only researchers but funders must provide these space and structure beginning in the study design phase. These findings are relevant in many places, but have particular importance for international, interdisciplinary teams working from various on-and-off-site locations with traditional or indigenous knowledge systems.

1. Introduction

Interacting productively and equitably with traditional communities to advance animal health and development goals has been a challenge for the scientific, veterinary, and development communities (Barnett et al., 2020). One key to successful collaboration is an accurate

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https://doi.org/10.1016/j.prevetmed.2021.105464
Received 30 November 2019; Received in revised form 6 August 2021; Accepted 10 August 2021
Available online 12 August 2021
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understanding of the community's knowledge and perceptions, including how the social power structures embedded in gender roles relate to livestock ownership and animal health (Njuki and Miller, 2013). A variety of methods have been employed to work with traditional knowledge systems, which range from questionnaire based approaches (Ole-Miaron, 2003); knowledge, attitudes, and practice surveys (Abdi et al., 2015); semi-structured interviews (SSIs); and participatory learning and action approaches (Fischer and Chenais, 2019). This manuscript explores the implications of the methodological successes and pitfalls encountered through unexpected findings from a mixed methods project that is ongoing in the Karamoja sub-region of Uganda. The hypothesis of this methodological analysis, exploration, and discussion is: by using a mixed methods approach including participatory epidemiology (PE), weaknesses and biases of individual methodologies can be mitigated and limited, improving overall understanding of subject matter.

1.1. The context of the research

The "Feed the Future *Peste des Petits Ruminants* Vaccine Associate Award" (PPR Project) is an effort to pilot a community-based delivery system for thermostable PPR vaccine for disease control and eradication in the Karamojong Cluster region, which includes adjacent parts of Uganda, South Sudan, Ethiopia, and Kenya. As the objective of the PPR Project is the proof of concept for a community animal health worker (CAHW) based delivery of a thermostable PPR vaccine for disease eradication, the overall project hypothesis was that an epidemiologically targeted and community-based vaccination campaign could achieve widespread disease control by eradication of virus hotspots in the Karamoja subregion of Uganda.

The Karamoja subregion of Uganda is located in northeastern Uganda, bordering South Sudan and Kenya (Fig. 1). The predominant tribes in Karamoja are sub-groups of the Karamojong and the Pokot. All groups practice transhumance, where livestock (primarily cattle, goats, sheep, and sometimes camels or donkeys) are kept in mobile camps commonly referred to as "kraals" (Stites et al., 2016). The Karamojong group of tribes speak dialects of an Eastern Nilotic language known as Ngikarimojong, and comprise three large communities within Uganda (Dodoth, Jie, and the Karamojong). The Pokot, another ethnic group in the region, speak an Eastern Sudanic Kalenjin language known as Pokot, and occupy a portion of southern Karamoja and an adjacent area in Kenya. Despite the livelihood similarities between these groups, there are also notable differences in their cultures. These are important to consider for research and development projects (Howe et al., 2015; OIE-FAO, 2015; Stites et al., 2016).

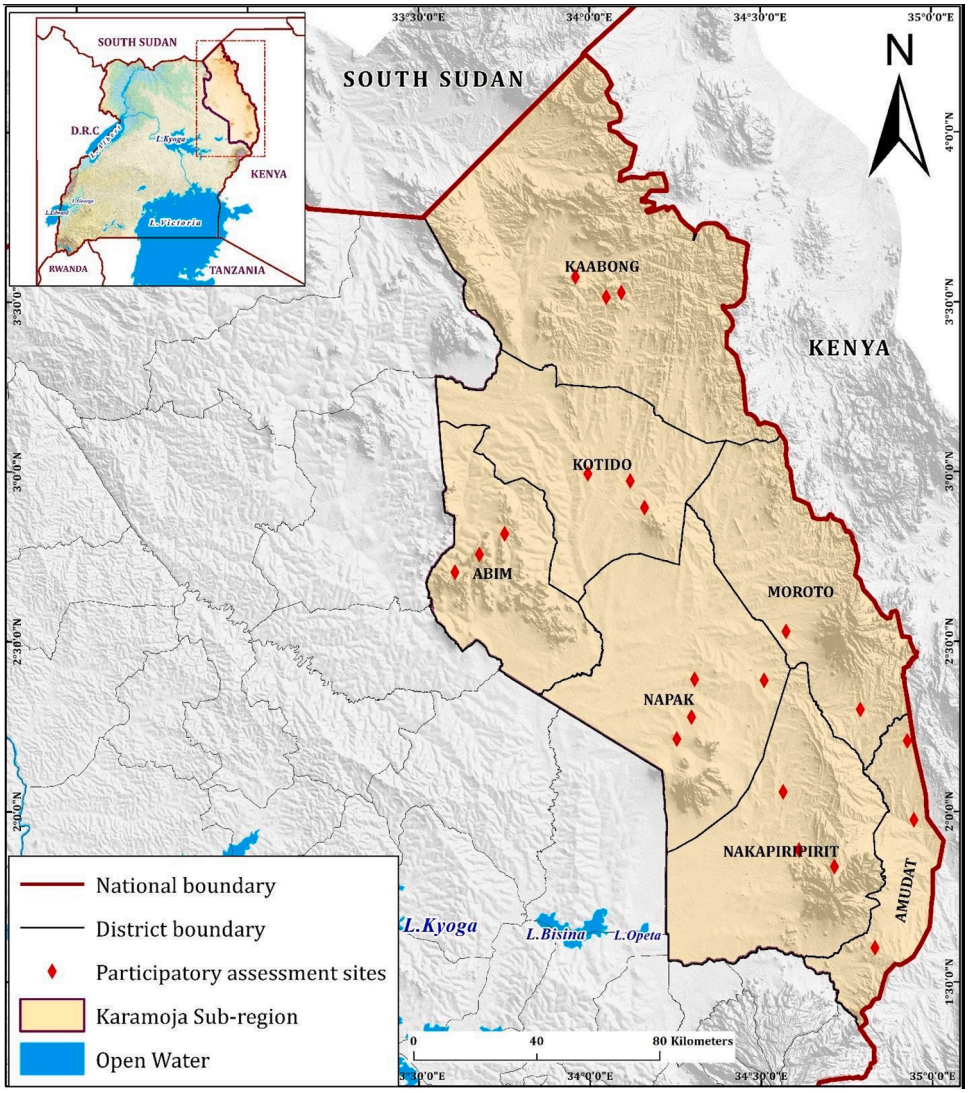

Fig. 1. Map of Karamoja with participatory assessments conducted as part of the PPR project site assessment marked.

1.2. Traditional veterinary knowledge

By virtue of living and working closely with their livestock, the pastoralists of Karamoja, like many pastoralist groups, have detailed traditional knowledge systems on animal diseases and health. However, understanding of and access to western veterinary medicine is limited by barriers in language, infrastructure, education, and professional veterinarian presence. On the other hand, the veterinary practitioners' understanding of traditional knowledge systems is often limited and may be highly biased by myths and rumors shared between professionals. Local disease lexicons do not usually distinguish diseases in the same manner as Western medicine, as they are usually based on commonly observed sets of symptoms, lesions, and epidemiological factors rather than the etiological agent responsible for the illness. For example, communities sometimes categorize different presentations of the same infection as different diseases (Catley et al., 2001). Furthermore, lexicons usually vary as dialects of local languages do, which sometimes leads to one disease being called by several different names within a small area (Jones et al., 2020).

1.3. Peste des petits ruminants

Peste des petits ruminants (PPR) is a disease of sheep and goats associated with serious impacts on the livelihoods and nutritional outcomes of livestock-keeping households across the African continent, as well as the Middle East and Asia (OXFAM/FAO, 2008; Jones et al., 2016; Spiegel and Havas, 2019). PPR is caused by the PPR virus, a member of the morbillivirus genus that includes rinderpest and measles (Balamurugan et al., 2014). PPR can be readily controlled by vaccination, but most PPR vaccines require cold chain up to the vaccination point. Recently, a thermostable PPR vaccine was developed which will enhance PPR control efforts (Mariner et al., 2017).

In PPR surveillance, the *pneumoenteritis syndrome* (PES) case definition is used, which entails a constellation of symptoms including an initial combination of runny and/or infected eyes and nasal cavities with runny and foul diarrhea leading to dehydration, followed by necrotic lesions and sloughing of mucosal tissues from mouth to anus sometimes including the respiratory system, finally progressing to pneumonia in severe cases (Balamurugan et al., 2014). Consistent use of the PES case definition reduces confusion and misinformation that can result from inaccurate or incomplete use of local disease terminology (Mariner et al., 2016). As traditional case definitions are syndromic in nature, rather than etiologic, the syndromic approach aligns well with PE, and PE has been highlighted as a key methodology to PPR disease control (Fischer et al., 2016).

1.4. Conceptual framework for mixed methods: household survey and participatory epidemiology

PE is one of several participatory methodologies that have emerged from the early techniques of participatory rural appraisal used in the late 20th century (Chambers, 1994; Jost et al., 2007; Fischer and Chenais, 2019). PE was first developed in the drylands of East Africa for utilization in detecting and controlling rinderpest in the late 1990s and early 2000s (Mariner and Roeder, 2003). The techniques have since been refined and documented (Jost et al., 2007; Catley et al., 2012; Alders et al., 2020), achieving relatively widespread acceptance in the veterinary epidemiology community (Bach et al., 2017), and continue to mature as a methodology. PE seeks to validate information by comparing knowledge gained from multiple respondents using multiple techniques, and may also involve statistical analysis. A key strength of PE is the ability to fully explore knowledge systems allowing respondents to express themselves within the context of their own world view. As new concepts emerge, the interview team is free to explore nuances and identify sources of bias. This imposes methodological limitations as well as being a strength. In its ideal form PE, (and all participatory methods) should be a capacity building process of co-learning for local partners and researchers; however, this can only be achieved through careful relationship building and sharing of decision-making through iterative processes (Gaventa and Cornwall, 2006; Fischer et al., 2016; Bach et al., 2019; Barnett et al., 2020).

The household survey (HHS) in the form of a questionnaire is a widespread data collection instrument used in many disciplines, allowing data collection on demographics, human and animal health, and socioeconomic indicators among others (Dohoo et al., 2012). The process of designing, tailoring, pre-testing, revising, field-testing (or piloting), finalizing, and administering the survey is an intricate and lengthy process essential to a well-designed instrument. A major strength of the HHS is its ability to engage participants individually, thus limiting social bias, and to collect information on a large population (Abowitz and Toole, 2010). The use of HHSs in mixed methods research often provides quantitative information on confounders and other indicators (such as race, sex, age, ethnicity) that may complicate or otherwise explain research findings. The HHS is strengthened when it is designed using qualitative formative research, such as information from key informant interviews or group SSIs and community validation (Glewwe, 2005). Common errors in survey research include coverage, sampling, measurement, and non-response errors (Ponto, 2015). Measurement error occurs when data collection strategies fail to capture the true state or status of the population being measured. Sampling error occur when the sample in a study does not represent the target population. These errors affect the reliability of a data collection instrument to accurately portray the target population.

1.5. Disagreement in results: discovering and analyzing errors

During data collection to operationalize and test the PPR Project hypothesis regarding PPR disease transmission and control, a set of unexpected methodological findings arose through comparative analysis of PE data collected during early site assessments with the HHS data, which were collected subsequently.

PE data and PPR surveillance were well aligned in the site assessment, but there were major disagreements between some PE data and HHS data, namely regarding local knowledge of PPR disease and awareness of PPR treatments. Also, there were what appear to be internal inconsistencies in HHS results in terms of disease and treatment awareness and the frequency of PPR disease reported and willingness to participate and pay for vaccination/treatment against PPR. Researchers investigated two potential sources of this conflict: sampling error and measurement error in the HHS. Multivariate regression models were used to test for associations between outcome variables and a range of potential confouders including enumertors and the sex of respondent. The observed associations are interpreted in light of findings from the PE, PPR surveillance, sociocultural formative research for HHS, and the logistics of research implementation. We reflect on the entire process, from study design and team composition to project communication and data collection, suggesting lessons learned for other researchers and veterinary practitioners, especially those working alongside traditional knowledge systems.

2. Materials and methods

When describing methods and findings, we use the word "*ijibijib*" – used by both the Karamojong and the Pokot - to represent both treatments (including vaccination) to clarify data collected in local languages. This is to represent the ambiguity that this word generated in our findings and to avoid misrepresenting the understanding that participants had about western medical terminology. The term *ijibijib* was found to be polysemic within the Ngikarimojong lexicon, including definitions that encompassed both treatment and prevention. When translated into English, *ijibijib* roughly translates as "injection," and refers to the method of delivery rather than the purpose (i.e. treatment or

preventive care) of the injection itself. In the questionnaire implementation, *ijibijib* was used to mean "vaccine/vaccination." With similar intent, we use PES (for pneumoenteritis syndrome) to report here, as an abbreviation for the set of local disease terms (Table 1) used in the field to communicate the presence of PPR.

2.1. Participatory epidemiology in the site assessment

The PPR Project began with a site assessment using PE, secondary data compliation, and enhanced surveillance for PPR. The site assessment was conducted in December 2017-January 2018. Only the PE-based findings from the site assessment findings are focused on in this paper.

The PE considered livestock-based livelihood challenges, communities' and individual's animal health knowledge, and the quality and availability of animal health services in the region. The main visualization techniques used were mapping, proportional piling, and timelines. SSIs with groups and individual key informants were conducted in the seven districts of Karamoja that existed at the time. The site assessment aimed at three group SSIs with kraal (livestock camp) leaders and livestock owners (persons who own livestock themselves), as well as three or more key informant interviews with veterinary drug shop owners and veterinary officials. Kraal leaders (who are usually men) and livestock owners were purposively selected to sample individuals known to be knowledgeable about pastoralist livestock keeping from communities principally reliant on livestock-based livelihoods. Group SSIs took place in locations both near to (< 5 km) and distant from (15−20 km) roads and were coordinated by asking to meet the groups "in the kraals, with the livestock keepers" with the aim of understanding active disease dynamics at that time. Group composition included women whenever women livestock owners were available, but data were not disaggregated by age or gender. However, when women and men were both present, gender dynamics were visibly active as women sat separately from and behind men, and often deferred to men or did not speak, highlighting the need for specific investigation of gender in the subsequent formative sociocultural research phase of the project. Key informant SSIs were held in town centers with animal health professionals, including governmental extension officials, district veterinary personnel, animal health workers, and veterinary drug shop owners active in Karamoja.

An appropriate amount of time was taken (typically between 15−30 min) within each interview to identify the terms used by the community for relevant diseases, using syndromic descriptions of diseases such as the PES case definition for PPR. A similar strategy was used to reach understanding about other key terms in Western medicine (ie. vaccines). Typical group SSI length was around 70 min; however, some extended up to two hours. Key informant interviews tended to be shorter, between 60−80 min.

SSIs were conducted by the authors in English with key informants such as government officers or drug shop owners, or in an appropriate local language (i.e. Ngikarimojong, Dodoth, Pokot) with livestock owners, kraal leaders, and drug shop owners with the assistance of several translators. Data were collected through notes and pictures, with consent. All SSIs for the site assessment were conducted following Makerere University, Tufts University, and University of Florida Institutional Review Board approved protocols including verbal informed consent and interview check lists tailored to each livelihood group interviewed.

2.1.1. Analysis of PE group SSIs

Group SSI data and key themes from the site assessment were analyzed and triangulated in facilitated discussions during the PDS training workshop and field training. They were also analyzed and triangulated at stakeholder meetings with veterinarians, CAHWs, and kraal leaders, which were held as part of workshops to discuss and agree to a business model for vaccination (logistics and costs) through facilitated discussions. Topics and themes that were highlighted during these stakeholder meetings were further triangulated qualitatively and spatially with information on PPR disease, livelihoods, and animal health services from other sources (i.e. secondary data sources and PPR outbreak surveillance).

Researchers identified two principle PPR hot spots in the Karamojong region by assembling evidence on the epidemiolgical scenario through the agreement of results from PE, along with data from PPR surveillance, PPR outbreak investigations, and phylogenetic findings on the viral strains responsible for the outbreaks. One hotspot was idendified in the north (Kotido/Kaabong Districts, home to the Jie and Dodoth Karamojong) and one in the south (Amudat District, home to the Pokot). The findings on the epidemiology of PPR within Karamoja and adjacent areas used to target the vaccine interventions have been analyzed and reported (Nkamwesiga et al., 2019). **The two detected hotspots were the sites for most subsequent project activities, including the HHS.** The selected sites for intervention within the hotspots were: (1) Nakapelimoru sub county (Kotido District – primarily a Jie area) and neighboring Loyoro sub county (Kaabong District - primarily a Dodoth area) in the northern part of Karamoja, and (2) Loroo sub county (Amudat District - primarily a Pokot area) in the south (Fig. 2).

Table 1
Table of local terms used for PPR Compatible PES by District.

Terms	Kaabong District	Kotido District	Abim District	Moroto District	Napak District	Nakapiripirit District	Amudat District
Loleo/lolio/olio	x		x	x	x	x	
Loleo ang' aknei		x					
Ali/loli ba karin/kareng		x					
Lourto/lourto konyen				x	x	x	
Lotulokun	x						
Lome/ome		x	x	x	x	x	
Lochit	x						
Losür (*Pokot*)				x			x
Lokiita				x			
Lomoo (*Turkana*)	x	x		x			
Eeleo						x	
Longorichino (*Tepeth*)				x			

Table 1 Terms in bold with grey highlighting are the terms that were suggested most likely to be helpful to HHS enumerators, within the districts indicated. The other terms were also reviewed during training. These terms were collected during the site assessment, and represent a wide (but not comprehensive) list of all of the terms used to describe PPR compatible PES in the subregion of Karamoja. All terms are in dialects of Ngikarimojong unless marked otherwise as Pokot, Turkana, or Tepeth. Note that the Karamojong people in Kaabong are primarily in the Dodoth tribe, while in Kotido they are primarily Jie. Amudat is home to the Pokot, but some Pokot also live in parts of other districts, such as Moroto. There are other Karamojong tribes not mentioned in this piece whose language and terminology are also represented here, and other tribes with whom the PPR Project has yet to interact.

2.2. Household survey in the baseline assessment

Understanding the methods behind the entire baseline assessment is foundational to this paper's discussion of methods. The baseline assessment collected data on goat and sheep serology through a serosurvey and, using two questionnaire surveys, associated sociocultural factors from a sample of households owning those goats and sheep in the two targeted hotspots (Fig. 2).

2.2.1. Design

To build the HHS, findings from the site assessment were used to design a secondary set of group SSIs for formative sociocultural research (i.e. SSIs were conducted in 3 locations in the north and 3 locations in

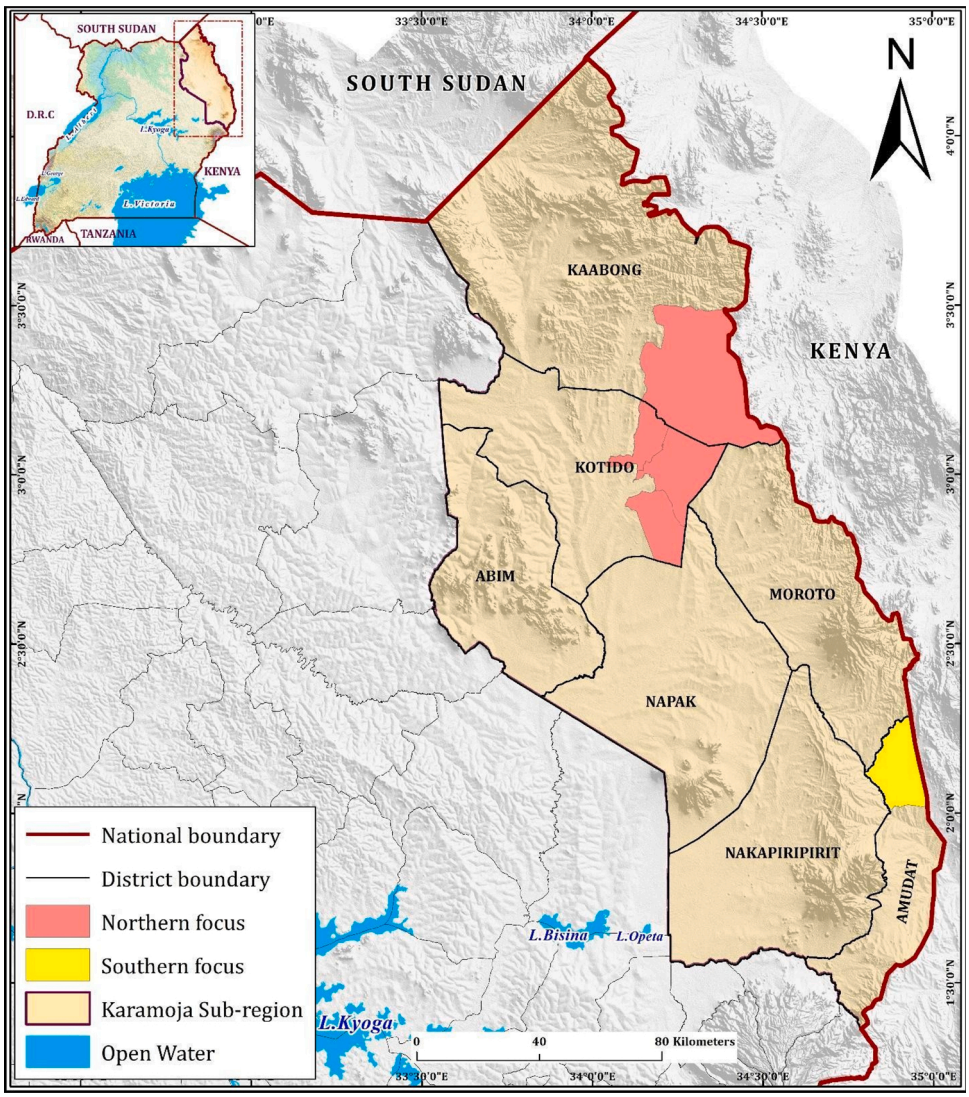

Fig. 2. Map of sites targeted for vaccination. The northern focus included two sub counties in adjacent districts and the southern focus comprised one sub county.

the south), to tailor the HHS and assess project sampling needs from a sociocultural perspective. Relevant recommendations (Moore and McKune, 2018) from this formative research included 1) heads of household should be the HHS respondents; 2) the A-WEAI (Abbreviated Women's Empowerment in Agriculture Index, a validated tool for understanding gender dynamics, see Alkire et al., 2013) should be conducted alongside the HHS; and 3) when mobilizing the Pokot in Amudat, efforts should focus on the men in the community, due to a reported lack of women's knowledge about and decision-making power in livestock rearing (Moore and McKune, 2018). The HHS was piloted and revised based on team feedback during enumerator training. Once finalized, the HHS and A-WEAI questionnaires were translated by a translation service in Karamoja into Ngikarimojong and Pokot and then back-translated to English by a different set of translators.

The finalized HHS questionnaire covered household demographics, livestock ownership of animal source food-producing livestock, knowledge of and attitudes about PPR vaccine - including willingness to inject animals, livelihood, human health and nutrition, dietary diversity, and gender empowerment (including household decision-making). Survey questions related to PPR disease knowledge and attitudes were developed with members of the epidemiology team to interrogate participant understanding around PES, PPR, Western medical terminology, and perceptions of vaccination, issues which were detected during the site assessment. The inclusion of the A-WEAI aimed to understand the roles of women (data not presented here) within the different ethnic groups in which the project would be implementing vaccinations.

The intensive baseline assessment of the targeted PPR hotspots paired questionnaire survey results with a serosurvey to provide the baseline for measuring the success of later PPR vaccination efforts. To optimize serosurvey data, 50 sampling locations were chosen by randomly generated GPS coordinates, 25 within each hotspot (Fig. 2). Within these locations, household level sampling for the questionnaires was designed to achieve a total of 500 HHSs and a subsample of 100 A-WEAI surveys. Household sampling was based on the formative research on the sociocultural factors concerning livestock husbandry and household dicision-making within the hotspot locations (formative research reported fully in Moore and McKune, 2018). Cultural differences in gender roles between the Karamojong and the Pokot were reported in the formative research. In contrast to the Karamojong, Pokot women were reportedly less able to answer HHS questions related to livestock and finances. However, Pokot women's representation was needed in the A-WEAI to investigate gender roles further. To accommodate these cultural differences in gender roles, two household level sampling methodologies were designed. (1) For the Karamojong in the northern Kotido and Kaabong Districts, 10 heads of household were to be recruited to answer the HHS (2 of the 10 should be women). Two women heads of household were to take the A-WEAI alongside the HHS. (2) For the Pokot in Amudat District to the south, only men were to be

recruited for the HHS, and in 2 of those households two women were to be recruited to complete the A-WEAI only.

As approved by the Institutional Review Board at the University of Florida, potential participants were read a statement on informed consent and verbally agreed to participate in the HHS/A-WEAI. The surveys were administered in one-on-one settings for privacy on encrypted tablets using the Survey123 electronic survey software by ESRI. The teams were supervised by a team leader in each district, who was also responsible for the quality assurance of survey administration and daily-upload of completed surveys to the encrypted server.

2.2.2. Training for survey data collection

Enumerators were hired based on their previous experience working on questionnaire-based projects and their command of both English and one of the two main local languages. Two teams were formed, one speaking Ngikarimojong for the northern hotspot and one speaking Pokot for the southern hotspot. Each team included three enumerators with secondary and post-secondary education and field experience. Each team was composed of two men and one woman—ensuring female participants would be asked questions by a female enumerator. Enumerators were paid by the day with a fixed daily target for the number of interviews.

Enumerators attended a three-day training facilitated by the sociocultural team, with assistance from a certified PE practitioner on the project team. The training included modules on human subjects research, questionnaire implementation best practices, and specifics of the study population, and the electronic survey software. During the training, the PE practitioner led training on what PES is, PES compatible terms (including those most likely to be helpful based on the site assessment – see Table 1), and how to clearly differentiate the concept of *ijibijib* as **preventative** treatment from *ijibijib* as **acute or emergency** treatment due to illness. Examples like injections for preventive tick treatments versus treating with injectable antibiotics could ensure mutual understanding. Despite this training, we cannot document that these efforts were consistently undertaken in the field. The training also included piloting both survey instruments (HHS and A-WEAI) at two sites (one per language), allowing enumerators to practice validating PES compatible terms.

2.2.3. Logistical challenges

Seasonality and spatial differences played an important role in the implementation of the baseline assessment. Both sites were experiencing severe flooding but due to topographical variation, this affected the data collection differently. In the north (Kotido/Kaabong Districts), widespread flooding meant the Karamojong chose to pull their animals into temporary multi-herd kraals for greater safety. Multi-herd kraals may include herds from ten or more households (with total animals observed visually estimated at over 20,000 in these cases), are typically run solely by men and boys, and tend to be more distant from the manyattas (semi-permanent settlements comprising of 2–10 households) where women are more typically present. This had important implications for implementation of the sampling methodology. The team was forced to sample from multiple households from the same multi-herd kraal (this was facilitated by coordinating with the head kraal leader(s)) and had fewer women complete the HHS than anticipated. The research team attempted to find women from corresponding households to complete the A-WEAI, but in some cases were only able to find women from other households around other sampling locations.

In the south (Amudat District), more localized flooding meant multi-herd kraals were not in use in the sampling area. Since the wet season migration pattern active at the time of the baseline assessment placed a large proportion of adult men 50+ km (where they were accompanying the household cattle and select goats and sheep) from the household manyattas within the study area, fewer men were available to participate than were outlined in the sampling frame, and those that were at the manyatta were not necessarily those most knowledgeable about livestock, as would have been preferred. Despite the defined sampling strategy to target men rather than women among the Pokot, more women were administered the HHS in Amudat District than men.

2.2.4. Baseline assessment data analysis

The data were collected using Survey123 by ESRI, while data management and cleaning were executed in Microsoft Excel and Open Refine. Variable recoding and analyses were performed using IBM Statistical Packaging for the Social Sciences (SPSS) and the statistical packaging software R (Version 1.0.153).

Descriptive statistics collected on the surveyed population were analyzed for the independent variables of interest, as well as the outcome variables of interest. Bivariate analyses were conducted to test each independent variable against each dependent variable for independence. Odds ratios were performed to examine the likelihood of outcomes, regardless of whether statistical significance was found or not.

2.3. Post-Hoc methods analysis

A multivariate multiple regression was run to predict awareness of PPR, awareness of PPR vaccine, and willingness to inject (*ijibijib*) against enumerator, age, sex, and ethnicity of respondent and if livestock is primary source of income in a household, with linear regression tests extracted separately to predict awareness of PPR as a disease, awareness of PPR vaccine/injection, and willingness to inject (*ijibijib*). It models responses of awareness and willingness with multiple predictors. P-values lower than 0.05 are considered statistically significant.

Three dependent dichotomous outcome variables of interest were examined—the awareness of PPR as a disease, the awareness of a PPR vaccine (ijibijib), and the willingness to vaccinate (*ijibijib*) household goats and/or sheep against PPR. The independent variables of interest examined were sex of the respondent, district in which respondent lives, marriage status, ethnicity, percentage of household income from livestock/goat/sheep production, household use of veterinary care for goats/sheep, and the type of care (preventative, emergency, or both) for goats/sheep. Considering cultural similarity and epidemiological entanglement, the two Karamojong tribes in the northern site (Dodoth and Jie) were treated as one ethnic group for collective comparison with the Pokot of the southern site.

A multivariate multiple regression model with linear regression tests extracted was developed to evaluate the relationship of independent variables (enumerator, age of respondent, sex of respondent, ethnicity of respondent, and primary income source as livestock) with three outcome variables of interest (knowledge of PPR disease, knowledge of PPR vaccine, and willingness to inject (*ijibijib*). Researchers employed this tool to investigate potential measurement and sampling error.

3. Results

3.1. Qualitative site assessment results

Qualitative results from the PE site assessment about local terminology, disease awareness, *ijibijib* awareness as a proxy for vaccine awareness, and willingness to pay for animal health care are presented in detail. Key themes from the site assessment are described here and illustrated by specific quotations from group SSIs and key informant SSIs. Critically, participant awareness of PPR disease and PPR *ijibijib* were two key areas of inconsistency between HHS and PE-based findings, while data on willingness to use *ijibijib* against PPR was an area of agreement between HHS, formative sociocultural, and PE data.

3.1.1. Description of site assessment participants

Data for the site assessment came from a total of 20 group SSIs and 23 key informant interviews (14 veterinary drug shops and 9 government officers) across seven districts. Additionally, the site assessment

included findings from 21 group SSIs conducted in Moroto District (home to northern Pokot, Matheneiko Karamojong) as part of a training on participatory disease surveillance, and from two group SSIs with migratory Turkana herders in Kaabong District (typically home to Ugandan Dodoth Karamojong).

The average group size was 11 attendees. Women were included, but the vast majority of participants (85 %) were adult men due to the purposive sampling. One group SSI (comprised solely of women) was met at a manyatta (a semi-permanent settlement comprising of 2–10 households) not adjacent to a kraal.

3.1.2. Awareness of PPR and the recognition of pneumoenteritis syndrome (PES)

Many livestock owner and CAHW group SSI participants demonstrated a high awareness of PES-compatible disease presence and impact on their livelihoods, sharing nuanced analyses of how animal health issues interact with each other. The results from disease ranking exercises illustrate this. Even where PES was reported by livestock owners as the most frequent/severe, it was not highly prioritized. In the presence of the high load of tick-borne diseases and/or pneumonia from all causes, PES was usually ranked "less important" by comparison. This was true even when reported losses from PES were substantial (i.e. reported mortality of 80 % + of young goats in PES outbreaks in Amudat). Livestock owners who had experienced PES compatible disease recently did rank it comparatively higher, but explained it was not their top concern, relative to the impact of the high overall disease burden on their livelihoods.

Participants also displayed awareness with highly differentiated and clinical-sign-specific nature of local disease terminology. Between 15–25 disease syndromes were typically reported during group SSIs, ranging from the mundane (*ngikur* or worms) to the economically damaging (*loukoi* or contagious caprine and bovine pleuropneumonias or CCPP and CBPP). Most diseases had one name that was relatively consistent across the region. Not so for PES: the site assessment found at least 12 names compatible with the PES case definition (see Table 1) in Ngikarimojong and one consistently used term in Pokot (*losür*). Some local terms compatible with PES were also partially or completely compatible with diseases caused by other pathogens or parasites (i.e. CCPP), and required careful probing during PE SSIs to tease out which disease and pathogen was the most likely culprit, as has also been recently found in other pastoralist areas (Jones et al., 2020). In explaining the terminology for diseases of concern, SSI participants described detailed clinical signs, consistent progression of disease, and debated amongst themselves the importance of associations between potential causes like environmental changes or interaction with other herds.

Participant disease awareness was validated through triangulation and analysis of different data streams. PE group SSIs during the site assessment indicated that disease compatible with PES is present in all parts of Karamoja, but with sizable variation in frequency and severity, an important epidemiological finding. PPR disease awareness from traditional veterinary medicine was corroborated by the location of PPR outbreaks occurring during the genomic analysis of PPR-virus and the serological survey from the baseline assessment (Nkamwesiga et al., 2019).

3.1.3. Awareness of interventions for PPR

Awareness of PPR *ijibijib* was evident from the extensive discussion about the availability and desireability of PPR *ijibijib*. Livestock owner reports of PPR *ijibijib* utilization and availability varied widely, even within different parts of the same district. Livestock owners were typically (but not always) aware of which diseases vaccination campaigns were targeting, for example describing a campaign was for *edjaa* (foot and mouth disease), *loukoi* (CBPP/CCPP), PPR-compatible PES, and anti-tick (acaricide) dipping/treatments. At the same time, many did not initially understand the distinction between a preventive and therapeutic treatment. Notably, a majority of livestock owners who reported PPR-compatible PES in their area (8 out of 13 group SSIs where PPR/PES was reported nearby) understood that injections against PES existed as part of campaigns – **a finding that conflicts with HHS findings**. In several interviews (7/20) PES was not reported and therefore probed minimally. Patchy or incomplete *ijibijib* campaigns (including those for PES) were reported throughout Karamoja. There was a higher concentration of PPR campaigns in the areas around Moroto District in 2015, 2016, and 2017—a response to the reported PPR outbreaks there at that time. Many group SSIs from various parts of Karamoja reported no recent *ijibijib* for PES, and some in more remote locations (i.e. 20 km or more away from roads) reported no *ijibijib* campaigns of any kind in 5+ years. Complete coverage by campaigns were not reported in any livestock owner group SSIs.

Livestock owners did have reservations about utilizing *ijibijib*, based on fears of animal injury. Previous campaigns had been associated with injuries or perceived to be associated with injuries, including previous campaigns including PPR vaccines. For example, participants in Amudat and Kotido complained that "…the tails fell off of the [livestock] that were *ijibijib*," and "There were… deaths from the *lome* (PPR-compatible PES) *ijibijib*." These specific concerns underscore that participants were aware of the existence of an injectable treatment for PPR, expressed in that example as "*lome ijibijib.*"

Nevertheless, many livestock owners expressed a desire for more frequent, regular, and predictable campaigns for all animal (and human) diseases, as well as ways to access *ijibijib* for PES outside of campaigns. Examples of how participants expressed this include: "campaigns are rare, [we] need more of them." Shortages of supplies during campaigns was also a frequent complaint from livestock owners: "they ran out before we came to participate." Findings about willingness to vaccinate here align with the HHS.

3.2. Baseline assessment household survey results

Results presented from the HHS are only those relevant to a discussion of the contradictions with findings from the PE and surveillance.

3.2.1. Description of survey respondents

A total of 545 surveys were collected amongst all participants; by district, 272 (50 %) were collected in Amudat (Pokot), 113 (21 %) in Kaabong (Karamojong Dodoth), and 160 (29 %) in Kotido (Karamojong Jie). In the south, Amudat district, the percentage of male HHS respondents was 36 %, while in the north it was 79 % and 83 % in Kaabong and Kotido districts, respectively. A total of 59.6 % (325) of survey respondents were heads of household. The average time to completion was 45−50 min, 10−15 min shorter than the anticipated length.

Goats were the most commonly owned livestock species, followed by cattle, and then sheep. For all livestock except poultry, men were overwhelmingly the primary owners of the animals. Livestock management for cattle, camels, sheep, and goats were all primarily performed by men, both adult and youth. Adult men were the primary decision-makers in all livestock species, with menial tasks of watering and grazing sometimes delegated to male youths. Adult women were primarily in charge of the care and decision-making for poultry.

Over ninety percent (93.6 %) of respondents owned or had an animal from their household having blood drawn for serology as part of the baseline serosurvey. For this analysis, this demonstrates that most HHS respondents were also the owners and/or caretakers of animals participating in the serosurvey, indicating the utility of using the serosurvey sampling strategy as the base structure for the HHS sampling strategy.

3.2.2. Awareness of PPR and the recognition of pneumoenteritis syndrome (PES)

Awareness of the presence of PES was assessed in the context of other impactful diseases. Most goat owners (74.3 %) reported having goats die

from illness in the past 6 months. The illness most commonly causing mortality was "*lokoi*," a term which is consistent with pneumonia caused by CCPP and other pneumonia causing disease agents. 79 % (377) of goat owners reported goat mortality from *lokoi*. The second-leading cause of reported goat mortality from illness was due to PPR-compatible PES (see Table 1 for list of local terms for PES used), reported by half of all goat owners (50.3 %; 241). Within the population, 82.1 % of respondents reported having sheep die from illness in the past 6 months. *Lokoi* was also reportedly to blame for the most sheep mortality, reported by 71 % (234) of sheep owners. The second-leading cause of sheep death from illness was due to PPR-compatible PES, reported by 69 % (226) of sheep owners.

Respondents reported that they were only moderately familiar with the local terms utilized by the enumerators for PPR/PES. Out of 541 valid enumerator-respondent responses, 277 (51.2 %) indicated knowledge of PES-compatible terms, while 264 (48.8 %) indicated no recognition of the terms used by the enumerators. A significant relationship was found between awareness of PES-compatible terms and respondent's sex, use of preventive care for goats, proportion of household income from goats, and the identity of the enumerator. Men were significantly more likely to report knowing about PES than women ($p = 0.039$). Within the surveyed population, nearly 55 % of men were aware of PES, while only 46 % of women reported awareness of PES. The odds ratio showed that women were 30 % less likely to be aware of PES as a disease than men.

However, differences between the level of awareness measured by each enumerator were significant, with some enumerators tending to find low awareness (23.1 %) and others high awareness (83.3 %). Overall knowledge of the disease correlated with enumerators. A chi-square test showed the association between reported awareness of PPR and enumerator collecting the data to be highly significant ($p < 0.000$, see Table 2).

3.2.3. Awareness of interventions for PPR

Enumerators asked respondents about their awareness of the PPR vaccine using the term "*ijibijib,*" and were trained to clarify what they meant by "*ijibijib*". A total of 8.81 % of respondents reported awareness of a PPR *ijibijib*. Of that 8.81 %, the vast majority were men (7.48 % of all respondents) though some women were also aware (1.32 % of respondents). The district with the highest awareness of the PPR *ijibijib* was Amudat, yet still only 8.5 % of the surveyed population knew of the vaccine. **In contrast to the site assessment**, where *ijibijib* for PPR was reported and discussed in 61 % of SSIs where the PES syndrome was mentioned, the majority of the survey population, over 91 %, reported no knowledge of the PPR *ijibijib*. These findings are in conflict with the qualitative PE data about *ijibijib* and vaccination campaigns.

A significant relationship was found between awareness of *ijibijib* and the variables (1) respondent sex, (2) utilization of preventive care for goats and sheep, and (3) lower levels of reliance on goat or sheep production for household income. Women were 80 % less likely to be aware of a PPR vaccine than men, those utilizing preventive care for household goats were 2.8 times as likely to be aware of the PPR *ijibijib* than goat owners not utilizing preventative care, and sheep owners utilizing preventive care for sheep were also 2.2 times as likely to have *ijibijib* awareness (Table 2). Meanwhile, the the odds ratios for proportion of income from goat and sheep production showed that respondents with lower levels of goat- sourced income were 2.5 times as likely to be aware, and lower levels of sheep-sources income were 1.5 times more likely to be aware. The chi-square test was not significant, but the odds ratio indicates that households where livestock production was the majority of their income were 1.3 times more likely to be aware of the PPR *ijibijib.* Ethnicity and marriage status did not have significant relationships with awareness of PPR *ijibijib.*

Regardless of reporting knowledge of either PPR or the PPR vaccine, respondents were overwhelmingly willing to receive *ijibijib* for their animals. However, this was the most skipped question within the HHS, with 25 % respondents not responding to the question. The highest percentage of willingness was reported in Amudat (Pokot), where the highest number of responses were recorded. Overall, 98.6 % of respondents who answered the question were willing to inject (*ijibijib*), with only 1.5 % saying they were unwilling. This could be conservatively interpreted that 73 % of all persons surveyed expressed willingness to participate in the administration of *ijibijib* for PPR to their goats and sheep. Findings about willingness to use *ijibijib* against PES aligned with the PE-based site assessment.

Table 2
Statistics for Relationships Between Awareness of PPR disease and injection (*ijibijib*) and Independent Variables.

Independent Variables	Awareness of PPR Disease		Awareness of PPR injection	
	Pearson Chi-Square p-value	Odds Ratio	Pearson Chi-Square p-value	Odds Ratio
Enumerator	0.000**	–	0.006**	–
Sex of Respondent	0.039*	0.698	0.000**	0.217
Ethnicity	0.604	1.903	0.824	0.935
Marriage Status	0.104	1.493	0.964	0.981
District	0.487	–	0.004**	–
HH Utilization of Preventative Care for Goats among Goat Owners	0.000**	2.546	0.001**	2.883
Smaller Portion of HH Income from Goats among Goat Owners	0.000**	2.260	0.008**	2.352
HH Utilization of Preventative Care for Sheep among Sheep Owners	0.345	1.235	0.023*	2.226
Portion of HH Income from Sheep among Sheep Owners	0.773	1.098	0.329	1.554
Portion of HH Income from Livestock among Livestock Owners	0.886	0.976	0.356	1.328

Significance:
* Where $p < 0.05$.
** Where $p < 0.01$.

3.2.4. Post-Hoc methods analysis results

Given the discrepancy in data generated by the PE activities of the site assessment and the HHS results, additional analyses were conducted to investigate the validity of the HHS results. A multivariate multiple regression model with linear regression tests extracted was developed to further examine the role that enumerator, age of respondent, sex of respondent, ethnicity of respondent (ethnicity is associated with location and district), and livestock as primary income had on three variables of interest (knowledge of PPR disease, knowledge of PPR *ijibijib,* and willingness to vaccinate/*ijibijib*).

Knowledge of PPR disease was highly associated with sex of respondent and marginally associated with the enumerator (Table 3). For knowledge of a PPR *ijibijib,* sex of respondent was again highly associated, while there was a marginal association with the age of respondent (Table 3). Finally, willingness to vaccinate/use *ijibijib* was highly associatied with sex of respondent and enumerator ($p < 0.01$), while ethnicity ($p = 0.033$) and livestock as primary income ($p = 0.077$) also showed moderate associations (Table 3). These findings are combined in a multivariate multiple regression model that examines the collective predictive value of enumerator, age, sex, and ethnicity of respondent, and if livestock is a primary source of income in a household on the three outcome variables. Results indicate that enumerator and sex of respondent are statistically significant predictors for reporting awareness of PPR, awareness of PPR *ijibijib*, and willingness to vaccinate/*ijibijib*, ($p < 0.001$) (Table 4). There is a positive correlation

Table 3
Linear Regression Test extracted from Multivariate Multiple Tests for Awareness of PPR Disease, Awareness of PPR Injection (*ijibijib*), and Willingness to Inject (*ijibijib*) against PPR.

Covariates		Awareness of PPR Disease			Awareness of PPR Injection (*ijibijib*)			Willing to Inject (*ijibijib*)		
		Estimate	SE	Pr(>|t|)	Estimate	SE	Pr(>|t|)	Estimate	SE	Pr(>|t|
Enumerator*	P1	0.079	0.228	0.729	0.107	0.150	0.475	−0.140	0.352	0.692
	P2	−0.332	0.227	0.145	0.033	0.149	0.827	−0.550	0.351	0.118
	P3	0.359	0.289	0.215	−0.152	0.190	0.423	−0.283	0.447	0.526
	P4	0.344	0.231	0.138	0.068	0.152	0.655	0.002	0.358	0.995
	K1	0.001	0.396	0.997	0.059	0.260	0.821	−0.549	0.612	0.370
	K2	−0.656	0.395	0.097 ‡	0.019	0.259	0.940	−0.421	0.610	0.490
	K3	−0.324	0.396	0.414	0.120	0.260	0.646	−1.710	0.612	0.005†
Age of Respondent		0.002	0.001	0.164	0.001	0.001	0.097‡	0.002	0.002	0.215
Sex of Respondent	Male	0.257	0.047	7.460e-08†	0.105	0.031	0.001†	0.213	0.073	0.004†
Ethnicity	Karamojong	0.372	0.552	0.501	0.004	0.362	0.991	1.536	0.853	0.072‡
	Pokot	0.159	0.450	0.723	0.051	0.295	0.863	1.485	0.695	0.033‡
Livestock as Primary Income	No	0.217	0.147	0.139	0.079	0.096	0.414	0.346	0.227	0.127
	Yes	0.224	0.147	0.126	0.088	0.096	0.359	0.401	0.227	0.077‡

Table 4
SE = Standard Error; Pr(>|t|) = P-value for *t*-test.
* P indicates enumerators who collected data from the Pokot; K indicates enumerators who collected data from the Karamojong.
† $p < 0.05$.
‡ $P<0.1$.

Table 4
Multivariate Multiple Test with Awareness of PPR, Awareness of PPR Injection, and Willingness to Inject (ijibijib) Results of a Multivariate Analysis of Covariates.

Effect		Value	F	p
Enumerator	Pillai's Trace	0.566	17.635	< 2.220e-16*
	Wilks' Lambda	0.515	18.824	< 2.220e-16*
	Hotelling's Trace	0.788	19.790	< 2.220e-16*
	Roy's Largest Root	0.470	35.646	< 2.220e-16*
Age of Respondent	Pillai's Trace	0.009	1.533	0.205
	Wilks' Lambda	0.991	1.533	0.205
	Hotelling's Trace	0.009	1.533	0.205
	Roy's Largest Root	0.009	1.533	0.205
Sex	Pillai's Trace	0.068	12.802	4.358e-08*
	Wilks' Lambda	0.932	12.802	4.358e-08*
	Hotelling's Trace	0.073	12.802	4.358e-08*
	Roy's Largest Root	0.073	12.802	4.358e-08*
Ethnicity	Pillai's Trace	0.010	0.863	0.521
	Wilks' Lambda	0.990	0.863	0.521
	Hotelling's Trace	0.010	0.863	0.522
	Roy's Largest Root	0.009	1.554	0.200
Livestock as primary source of income	Pillai's Trace	0.010	0.845	0.535
	Wilks' Lambda	0.990	0.845	0.535
	Hotelling's Trace	0.010	0.846	0.535
	Roy's Largest Root	0.009	1.643	0.179

Table 5
* $p < 0.001$. Pillai's Trace, Wilk's Lambda, Hotelling's Trace, and Roy's Largest Root are multivariate multiples tests use to analyze covariates.

between being male and reporting an awareness of PPR, an awareness of PPR *ijibijib*, and a willingness to inject *against* PPR (*ijibijib*) (Table 3). Pokot ethnicity is positively correlated with a reported willingness to vaccinate/*ijibijib* (Table 4).

The relationship between enumerator and sex of respondent is explored further in Fig. 3, providing additional support for discussion of

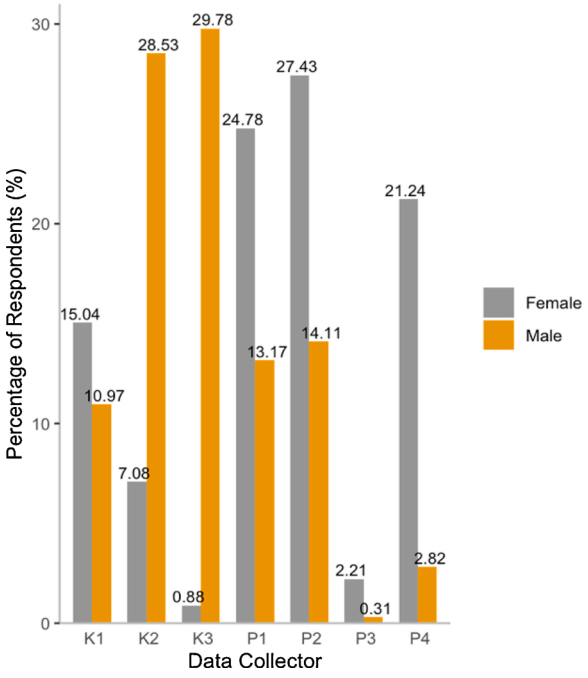

Fig. 3. Percentage of Participants Interviewed by Each Enumerator Grouped by Sex.

both sampling and measurement error. Fig. 3 shows relative percentages of the gender of interviewees. More women than men of Pokot ethnicity were interviewed and more men than women of Karamojong ethnicity were interviewed. Fig. 3 also presents the relative percentage of men and women interviewed by each enumerator within each ethnic group.

4. Discussion

4.1. Study design versus implementation

4.1.1. Sampling error

Sampling errors occur when the sample in a study does not represent the target population. While the improved reliability and validity of mixed methods research is lauded (Abowitz and Toole, 2010; Teddlie and Yu, 2007), the risk of sampling error remains (Bazeley, 2004).

Formative research in the southern study site in Amudat District (with the Pokot) demonstrated a lack of livestock knowledge and husbandry among Pokot women, and underscored the need to target the male heads of household when measuring livestock management knowledge amongst the Pokot. Due to limited availability of the Pokot male heads of household, and perhaps an effort to over achieve on completing A-WEAI's, most survey respondents in Amudat were female, which likely led to significant sampling error. The inverse occurred in the northern study sites and the HHS was disproportionately administered to more men than women—despite sociocultural formative work (Moore and McKune, 2018) which reported that Karamojong women may be heads of household and are often caretakers of livestock and possess the knowledge to answer animal health focused questions. Furthermore, the survey was designed to be administered to the primary caretaker of the livestock which was determined to be the head of household in both ethnic groups; however, only slightly more than half of HHS respondents were heads of household. This combination, with emphasis on the contribution of a high number of Pokot women being engaged as HHS respondents, had important implications for sampling error in the HHS findings. The finding that sex of respondent was highly significant in all of the multivariable analyses supports the presence and significance of sampling error in explaining the presence of discordant findings between the HHS and the PE (site assessment) data.

Another layer of sampling error may have occurred via a disconnect between the sampling frames for site assessment (PE) and baseline assessment (HHS), which could have contributed to the observed discrepancies. The site assessment (PE) was designed to detect knowledge of PPR and perceptions of the animal health system throughout the Karamoja sub-region to enable epidemiological targeting and vaccine delivery design, requiring a purposive sample of people knowledgeable about livestock and animal health (i.e. livestock owners, heads of households and communities like kraal leaders and elders, CAHWs, drug shop workers, and veterinary officials). The geographic sampling strategy employed during the baseline assessment was appropriately designed around its serosurvey component, as the primary outcome of the study is herd immunity to PPR. It was, consequently, important to link the HHS with those participating in the serosurvey. The HHS was administered to a convenience sample of people surrounding the randomly generated location, which differed from the types of persons who participated in the site assessment. As previously stated, efforts to target heads of household with the HHS were inadequate, so differences between those providing information at site assessment and those providing information during HHS was greater than planned or anticipated.

Community-based participatory approaches like PE select key informants that are well placed to provide insights into the study question, whereas household survey methods aim to reflect a more generalized population (Davis and Whittington, 1998). In this case, the site assessment was targeted at understanding the terminology and epidemiology of PPR as well as its context in the local animal health systems and so mainly relied on animal health decision-makers; the HHS was aimed at understanding the demographics and perceptions of *subsets* of Karamojong and Pokot people based in the areas targeted for vaccination; these were valid choices for this project. The differences between the population of participants from the site assessments PE (kraal leaders, among others) and those surveyed for the HHS (significant portion of non-heads of household), may have contributed an additional layer of sampling bias, which could have contributed to the difference in findings but can only explain it in part.

4.1.2. Measurement error

Measurement error occurs when data collection strategies fail to capture the true state or status of the population being measured. In HHSs, there are four main sources of measurement error - the questionnaire, the data-collection mode, the interviewer, and the respondent (Kasprzyk, 2005). Measurement error is an extremely important consideration in cross cultural research, where qualitative or quantitative measures may not target the same construct (Boer et al., 2018). In this study, it is important to note that the serological data, risk maps, and genomic data all validated the results of the PE-based site assessment. In other words, these quantitative data confirmed that the disease reported by the PE SSI participants was where they said it would be. This validated those results and demonstrated a well-developed knowledge of PPR-compatible PES in the population and an ability to recognize the disease. These patterns described by herders were further validated by the occurrence of active outbreaks of PPR, detected through the PPR Project's enhanced surveillance techniques (Nkamwesiga et al., 2019).

In this study, the language itself was the measurement tool for several methodologies, including the formative PE, formative sociocultural work, and the HHS. Therefore, misunderstandings between researchers and community members about the meaning(s) of terminology are potential sources of measurement error. Here we highlight the likely misunderstandings suspected of producing measurement error. This highlights the challenges of accurately understanding information contained in traditional knowledge.

The presence and widespread use of many local names for the PES used by the Karamojong does not indicate a lack of disease presence or a lack of knowledge; more likely it reflects the diversity of language and abundance of similarly presenting diseases in the region. Moreover, a very similar situation has recently been documented in the Afar pastoralist communities of Ethiopia (Jones et al., 2020). The level of knowledge about PPR disease, its epidemiological patterns, and its common comorbidities demonstrated by the pastoralists during the site assessment is an important resource in surveillance and control activities that needs to be correctly understood in context.

The results of the site assessment SSIs indicated that interventions for PPR compatible PES control are known to exist and desired by livestock owners. This made the HHS finding that less than 10 % of respondents were aware of PES *ijibijib* surprising. It may be an artifact of the way information was requested (use of language, probing questions, etc.), the complexity of the area of knowledge, the methodology (direct survey questions compared to discussions), or personnel used to administer the survey instrument; it could also have been driven or exacerbated by sampling error. This makes the HHS finding of minimal awareness of PES *ijibijib* very hard to interpret in terms of local knowledge.

As previously noted, *ijibijib* is used in a way similar to non-specific terms like "shot" and "jab," so is it can mean vaccine or vaccination in the layperson's lexicon, but the term is also locally used for any type of treatment involving an injection . The practice of term identification is a key part of PE, and particularly critical when PPR is the targeted disease due to its nonspecific signs (Jones et al., 2020). Similarly, terms need to be consistently clarified in all research methods working with traditional knowledge systems in order to assure mutual understanding between the research team and participants. In the PE term identification typically took between 5–15 min as part of a 70−80-minute interview. Enumerators were trained to take time to identify the appropriate local terms to describe the syndrome and its symptoms, however the extent to which this occurred was not documented. The HHS was designed to be completed in 60 min, which was validated during piloting, but most surveys were completed in 45–50 min, calling into question whether effective communication between enumerator and participant was consistently achieved. The high significance (Table 2) of the association between reported awareness of PES-terms and enumerators also supports this analysis. Additionally, one section of the survey, designed to improve terminology understanding, was frequently not completed, which may indicate that some or all enumerators deprioritized terminology clarification in favor of completion of surveys. Finally, there were several areas of agreement between the HHS and PE, for example those on animal care practices, which did not depend on clarifying the meaning of *ijibijib* or the PES-compatible terms.

Despite explicit training that it was important take time for clarification in each questionnaire interview, some enumerators seem to have

rushed through the survey. An important reason for this was the unusually severe wet season: for physical safety field teams needed to be as efficient with time as they could be. Therefore, it seems unlikely the documented time taken to complete the HHS allowed for the kind of consistent clarification called for by this study's design, comparable methodologies (Teddlie and Yu, 2007), or work in comparable contexts (Jones et al., 2020).

4.2. Lessons learned and recommendations

The lack of internal and external validity in portions of the HHS data, despite the research team's extensive application of best practices in its design and implementation, have important implications for other researchers and practitioners, including but reaching well beyond those interested in global eradication of PPR to animal and human health more broadly. SSIs are often used as formative research to develop and tailor later quantitative data collection (often in the form of surveys; Dohoo et al., 2012), as was implemented in this project. It is often assumed that by using these approaches jointly that the resulting data provide a more complete representation of the surveyed community through methodological triangulation of multiple data types and perspectives. Importantly, both the consistent findings between PPR sociocultural team's formative data findings and the HHS results and the successful discovery and exploration of findings that disagree reflect the value of this approach. Nevertheless, the HHS appears to have suffered from two layers of sampling error, affecting the internal and external validity of the findings. First, there was an important difference in populations sampled by each team during their respective formative work; second, the HHS sample failed to effectively target and enroll participants who had been identified as most likely able to answer the necessary questions. Moreover, measurement error appears to have also occurred, based on significant associations between outcome variables (questions) and certain enumerators and, importantly, the short amount of time taken to complete the surveys. These could have contributed to the HHS's lack of internal validity. Both sets of problems occurred, despite formative research and iterative development of the survey, with input from the PE team, NGO partners, and project managers, and tailoring after training and pilot testing.

The key methodological insight is that all components of this mixed methods project were vital. The use of the HHS was, in this case and context, insufficient as a stand-alone data collection tool but also provided gender disagregated data vital to project success that are not reported here (i.e. livelihoods, demographics, and nutrition). The PE provided an indepth understanding of traditional knowledge about animal diseases, including their epidemiology, treatment, and the surrounding animal healthcare context. Without a substantive mixed methods project, including both the participatory site assessment work and formative qualitative research as part of the HHS's development, the HHS data may never have been fully interrogated. Only by seating the data from the baseline HHS in the context of the PE was the research team made aware of error in the administration of the HHS. Then, by triangulating complementary data from several data collection methods, both the epidemiological and sociocultural data, and reviewing the implementation strategy of each iterative phase of the research, the team gained insight into the nature of the sampling and measurement error confounding the inconsistent findings.

This illustrates that even having clear sampling and research methodologies and provisions for oversight can be insufficient to ensure quality data in the face of international, interdisciplinary teamwork and the complex logistical realities of fieldwork and valid data collection. Planning the study design is accepted as a vital component of any successful research project; however, planning the implementation and—most critically—designing an effective, team-focused process for revisiting and trouble-shooting the implementation of each phase of an iterative, adaptively managed project are equally important to the overall success of the research. Modern international research does not automatically foster the close interpersonal collaboration necessary to design and implement complex research designs, particularly in the wake of safety concerns surrounding the COVID pandemic. Key components of our research findings and their interpretation, which led to our exploration and conclusions about error, are discussed below. These have important implications for the implementation of mixed methods, international, interdisciplinary research projects which are vital to addressing the most complex challenges (Brown et al., 2010; You, 2017).

The realities of international, mixed methods, interdisciplinary research dictate that all team members have to make concerted efforts to be available to each other across difficult time-zones and internet connectivity issues, in addition to bridging disciplinary differences in perspectives on research and implementation. This is a non-trivial challenge and cannot be simply wished away through intentions for "good" communication (Barnett et al., 2020). Clear-eyed and iterative use of tools such as the causal map (also called directed acyclic graphs in epidemiology, (e.g. Textor et al., 2011)) to identify expected areas of weakness, followed up with effective, strategic coordination at all levels of project function are needed to address this weakness effectively. Explicit efforts to overcome disciplinary gaps exist; one such example is the Toolbox Dialogue Initiative, a research and outreach endeavor that engages members of interdisciplinary research teams in a facilitated process of communication and collaboration (Crowley, 2014). It calls on researchers to honestly reflect on their own positionality and the obstacles and opportunities that their perspective brings to interdisciplinary research and practice. Such coordination and habitual reflection must include clear definitions of team member roles and expertise and identified channels for communication. To give concrete examples of how this could have applied to this project: to the extent that male participants were at all available in the south, surmounting this sampling challenge would have required a dedicated protocol for real-time, team-based trouble-shooting of the methodology, ideally within a platform linking field team leaders to project coordinators and remotely advising scientific experts in one discussion space, such as a WhatsApp chat group or similar. Furthermore, achieving this with team members from differing professional cultures (i.e. hierarchical and collegial) requires specific effort, since "normal" communication channels for one culture can often be "abnormal" for the other.

Regarding the sampling error observed in the questionnaire survey findings, when project oversight for data collection in the field is overseen by implementing partners, such as NGOs, their practice-based, hands-on approach to trouble shooting barriers confronted during field work—an asset of the best of implementing partners—may prompt changes or adaptations that are *practical*, yet in conflict with theoretically driven decisions or design (i.e. sampling methods or recruitment of participants). Particularly if these members are not part of the project design, limitations to or consequences of deviation from protocol may be less apparent at the time when these decisions are taken. Divergence from the sampling frame and its recommendations presumably contributed to the lack of internal validity between HHS data results and data from the PE. In reference to both types of error observed, it is imperative that team members at all levels feel that they have a voice and that they are integrated into the research design and implementation process as much as possible, so that informed decisions can be taken – this is as true on the research team as it is in the field for participatory epidemiology or One Health (Ebata et al., 2020). Only when they are empowered and feel safe communicating with all members of the team will they be able to participate effectively in real-time quality control. Similarly, further reducing measurement error requires detailed and robust planning of implementation, including a discussion of how to set enumerators up for success, to ensure adequate time taken during questionnaire administration for mutual understanding between participants and the research team. Nevertheless, the role of interpretation that is necessarily part of the role of translators and enumerators cannot be forgotten during data analysis, even with the best study design and most pristine implementation.

4.2.1. Importance of mixed methods to research involving traditional knowledge

Our research team's effort to understand the origin and explanation for differences in our findings delivers an important message for researchers and development professionals when choosing methodologies used for data collection. Specifically, mixed methods approaches are not failsafe and yet they facilitate discovery of error. Surveys may fail to provide internally valid data, *even* when they are preceded by formative, qualitative research and are adapted and tailored accordingly. Participatory methods, *even* when they are implemented with iterative, collaborative community relationships and negotiations, will provide vital cross-checks but may not be sufficient to explain all sources of inconsistent findings. Without the diversity of data collected in the project, the retrospective analysis of contradictory findings would not have been possible.

The findings and methodological insights for interdisciplinary research where traditional knowledge is widespread can be summarized in four key recommendations: (1) utilize balanced mixed methods approaches, including qualitative, situated, participatory methods with quantitative methods aimed at both sociocultural and biological processes; (2) develop a communication plan capable of communicating across time, cultural, and disciplinary differences to ensure that the optimal mutual benefit of interdisciplinary research is realized; (3) build responsive team structures capable of adapting appropriately to both logistical challenges as well as emerging research findings, which are both inevitable in complex research agendas, and (4) be alert to emerging sampling and measurement biases to limit to every extent possible. In the design phase, it is essential to work together with representatives of each disciplinary and implementation team to develop causal maps that identify potential sources of biases and confounders, such as language, enumerator, or culturally defined mental models. These findings complement the call for space, within methodology and funding, for iterative participatory inquiry coordinated between community members and all parts of the research team (Ebata et al., 2020), and the importance of considering gaps along the entire value chain of research and how that affects issues of equity and validity (Barnett et al., 2020). These findings are particularly relevant and potentially applicable to any place where traditional or indigenous knowledge is widespread; where such traditional veterinary knowledge dominates or replaces western veterinary knowledge, they are essential learnings. They also have broad implications for research on knowledge, attitudes, and practices conducted in traditional communities and their application to developmental and community goals.

Funding

The PPR Project, or *Peste des Petits Ruminants* Vaccine Associate Award [No. AID-OAA-LA-17- 00001], is funded by the US Agency for International Development through the Feed the Future Livestock Systems Innovation Lab [No. AID-OAA-L-15-0003] at University of Florida Institute of Food and Agricultural Sciences.

Declaration of Competing Interest

The authors report no declarations of interest.

Acknowledgements

This project would have been impossible without the generous contributions of time, expertise, and resources provided by partners at District and Sub County local governments in Amudat, Kaabong, and Kotido; regional offices of the Ministry of Agriculture Animal Industries and Fisheries; Mercy Corps Uganda; the Participatory Epidemiology Network of Uganda; the College of Veterinary Medicine Animal Resources and Biosecurity at Makerere University Kampala, and most importantly the enthusiastic support of the local communities that deal with cyclical outbreaks of animal diseases. It is also specifically indebted to research technicians, enumerators, translators, technicians, and drivers; with special thanks to the technical expertise of Dr. David Nelson Okello and Francis Lomongin, as well as our indefatiguable translators Charles, Susan, Francis, Joseph, Moses, James, Joyce, and Zephaniah. Thank you all.

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