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Local epidemiology, impact and human response during an African swine fever outbreak in a rural village in Northern Uganda

Erika Chenais [a,b,*], Alfredo Acosta [a], Tonny Aliro [c], Alfred Ojok [d], Karl Ståhl [a], Klara Fischer [b]

[a] Swedish Veterinary Agency, Uppsala, Sweden
[b] Swedish University of Agricultural Sciences, Uppsala, Sweden
[c] Faculty of Agriculture and environment, Gulu University, Gulu, Uganda
[d] Independent scholar, Nwoya, Uganda

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ABSTRACT

This study investigated local epidemiology, impact and actions taken by smallholder pig farmers during an outbreak of African swine fever (ASF) in rural Uganda. Data collection included the biological sampling of sick or dead pigs, structured interviews using a questionnaire and geospatial records of risk locations for ASF. Following confirmation of the presence of ASF virus by conventional PCR, all households that reported pig deaths were considered ASF positive. Data analysis used descriptive statistics and content analysis of questionnaire data. The spatial distribution of positive households, risk locations for ASF and pig populations were analysed using a hexagonal grid; retrospective space-time permutation was used to detect spatio-temporal clusters. Of the 128 pig-keeping households in the study village, 61 ASF positive households were identified. Out of these, 43 reported selling and 34 consuming dead pigs. Three households reported disposing of carcasses in a safe way (in a latrine or by burning). The pig population in the ASF positive households was reduced by 48 %, compared to a reduction of 2 % in the ASF negative households. The reduction in pig population was spatially interconnected on a hexagonal level and associated with high pig density hexagons at the start of the outbreak and with the presence of risk locations for ASF (trading centres, pork restaurants and slaughter slabs). Two significant spatio-temporal outbreak clusters were detected. The opportunities to study ASF in smallholder settings in the immediate temporal connection to outbreaks are rare and the study gave unique insights that deepen the epidemiological and social understanding of ASF in the smallholder context.

1. Introduction

Pig farming is common in Uganda, with the majority of pigs kept by poor smallholders in rural and semi-urban areas (UBOS, 2020). Free-range management systems with low levels of biosecurity represent the dominant form of pig husbandry (Ouma et al., 2013). African swine fever (ASF), a viral disease affecting domestic pigs, typically with severe clinical signs and high mortality, is endemic in Uganda. The agents in the sylvatic epidemiological cycle (warthogs and *Ornithodoros* spp. ticks) are present in many parts of Uganda and the presence of ASF virus has been confirmed from ticks (Plowright, 1981; Mulumba-Mfumu et al., 2019). However, as in most ASF outbreaks globally, spread occurs mainly in the domestic pig epidemiological cycle (Dione et al., 2016; Chenais, 2017; Penrith et al., 2019). In this setting, it is the daily activities by stakeholders along the smallholder pig value chain (farmers, traders in live pigs or pork, slaughterers and consumers) that drive disease spread (Penrith et al., 2013; Nantima et al., 2015).

Epidemiological investigation and analysis of ASF outbreaks provide important information advancing knowledge about local epidemiology and the impact of outbreaks. As humans have key roles influencing ASF spread, outbreak dynamics and control, it is important to increase the understanding of the role and rationale of human behaviour and actions in these situations. This calls for studies of human behaviour in outbreak situations. Since human behaviour is socially and culturally shaped, behaviour and actions relating to outbreak and disease control are to some degree context specific. To ensure the cultural relevance and effectiveness of disease control policy, surveillance efforts, biosecurity advice and research priority agendas, it is important to reveal general as well as context-specific patterns of human behaviour in outbreak situations.

* Correspondence to: SVA, Uppsala S-751 89, Sweden.
E-mail address: erika.chenais@sva.se (E. Chenais).

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As yet, epidemiological studies of ASF outbreaks in smallholder settings, as well as studies focusing specifically on understanding the social and cultural aspects of human behaviour during outbreaks, are rare. There are several reasons for this. For the authorities or researchers to be able to investigate outbreaks and collect data, outbreaks need to be reported. In low-income settings, the reporting of infectious diseases is often erratic (Bendali, 2006). In Uganda, non- and under-reporting of ASF has previously been discussed by some of the authors of this paper (Chenais et al., 2015). Disease reporting is affected by many factors including willingness to report, low access to veterinary health care and logistical challenges involving, for example, getting samples to the laboratory on time. These hindering factors are especially pronounced for poor smallholders (Ilukor et al., 2015; Arvidsson et al., 2022a). The willingness to report ASF outbreaks might be further negatively affected by the fact that, even if investigations are made, results might not reach the affected pig-keeper or be perceived as useful. If outbreaks are reported to the animal health authority at all, it is often with a delay. This makes it impossible to take biological samples, as pigs have often already been sold or slaughtered upon the first rumours of outbreaks in order to reduce the losses for farmers and traders (Dione et al., 2016; Aliro et al., 2022). The delay also makes it difficult to collect accurate information on human behaviour, as studies have to rely on people's recollection of past events (Tourangeau, 1999).

This study investigated the local epidemiology of an outbreak of ASF in domestic pigs in a rural village in Northern Uganda with the objective of improving knowledge about local ASF epidemiology, disease impact and how people perceive and act upon an ASF outbreak in resource-constrained smallholder settings.

2. Materials and methods

The study consisted of an initial outbreak investigation including field observations and biological sampling. This was followed by face-to-face structured interviews with pig-keeping households and the gathering of geospatial data. We gathered geospatial data of locations that based on previous knowledge of the area and patterns of disease spread constitute risks for ASF spread. This included pig-keeping households and places for activities in the pig value chain such as the slaughter of pigs, sale of live pigs and pork, and the consumption of pork (Costard et al., 2009; Penrith et al., 2019).

2.1. Study area

The study was carried out in a rural village (the village name is anonymised to protect the participants) in the Nwoya district in the Acholi subregion of northern Uganda (Fig. 1). A "village" is the smallest administrative unit in Uganda and often consists of one or several trading centres, sometimes school(s), church(es) and surrounding settlements, which can be rather sparsely spread. The study village consists of approximatively 1500 people in 400 households.

People in rural Uganda are generally poorer than the national average and villagers often keep small, mixed herds consisting of several animal species in subsistence farming systems on small plots of land (Ampaire and Rothschild, 2010). Northern Uganda is one of the poorest regions in the country, with poverty being exacerbated by a period of civil unrest lasting from 1986 to 2006, ending with an unofficial peace agreement (Branch, 2013). Here, pig farming has been increasing, encouraged by the government and donors as a pathway out of poverty (Arvidsson et al., 2022b). Pig herd size is generally very small and most pigs are kept in free-range management systems on smallholder subsistence family farms (Chenais et al., 2017). The study village has been the subject of several previous studies concerning ASF and pig keeping, see for example Kukielka et al. (2016), Payne et al. (2021), Arvidsson et al. (2023). As a consequence, the researchers are well connected in the community and were informally notified of the outbreak that is the subject of this article.

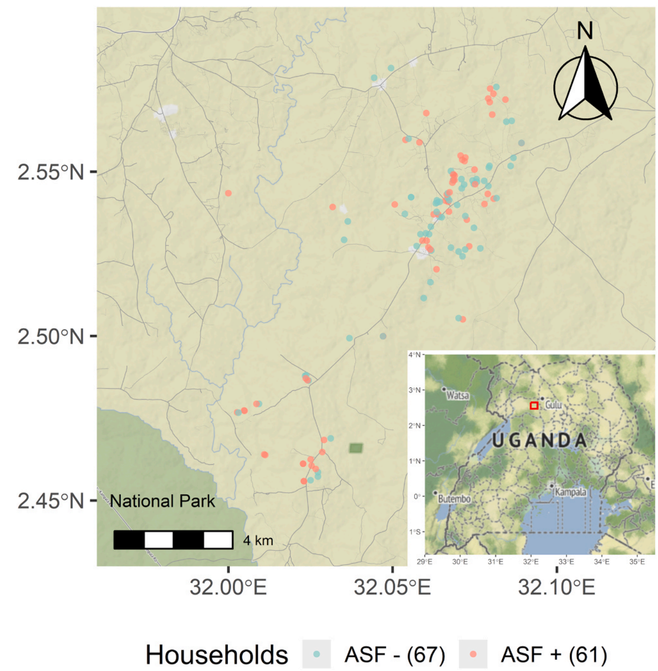

Fig. 1. A map visualising the locations of households included in a study investigating an outbreak of African swine fever (ASF) in northern Uganda in 2024. ASF positive households (ASF +) are marked with red dots and ASF negative households (ASF -) with green dots. The case definition used in the study was: ASF positive households=households that reported pig mortality during the time under investigation. On the bottom right corner a reference map shows the location of the study area marked as a red square on a map of Uganda. The map was created in 'R' (R core team, 2023), using 'ggspatial' and 'ggmap' packages.

2.2. Data collection

Upon receiving information about an ongoing outbreak with pig mortalities in the study village and several neighbouring villages, initial outbreak investigations were carried out on 13th February (neighbouring village) and 10th March 2024 (study village). These investigations included talking to village leaders, visiting affected households and taking samples from their pigs. Households in which all pigs had died or which had no reported mortalities were not visited. From live pigs, whole blood samples were collected in EDTA-coated sterile vacutainer tubes from the jugular vein. From dead pigs (if available), tissue (spleen, lymph nodes, muscle or bones) samples were collected. The tissue samples were put in sterile cryovials and bones in a plastic bag. Samples were put on ice in cool boxes and transported by car to the College of Natural Sciences (CoNAS) at Makerere University for laboratory analysis.

Following the initial investigations, structured face-to-face interviews using a questionnaire (see Supplementary material 1) were performed between March and July 2024. The questionnaire was designed in English and translated to Luo, the language spoken locally. Questions were tested in pilot interviews in a nearby village and adapted to ensure that they made sense to respondents and captured the dimensions of the outbreak under study. The aim was to reach all households in the village that kept pigs prior to the outbreak. Village leaders were consulted to create a census of pig-keeping households and all households listed by village leaders were interviewed. The interviews targeted adult household members available at the time who had sufficient knowledge of their household's pig keeping. Prior to participating, the respondents were informed of the purpose of the interview and the expected outcome of the study, asked for their oral consent and informed that they could withdraw their participation at any time for any reason. Interview responses in Luo were simultaneously interpreted and noted down in English by hand on hard copies of the questionnaire. The locations of the households interviewed were collected using a handheld GPS (GARMIN GPSMAP 78 s, Garmin Ltd, Olathe, Kansas, USA) and the GPS coordinates were noted. Responses noted on hard copies of the questionnaires, including the GPS coordinates, were subsequently digitised for data processing via single entry into a Microsoft Excel spreadsheet (Microsoft, Redmond, WA, USA). Following this, data were verified for completeness and accuracy before analysis. Finally, geospatial data of risk locations for ASF spread along the pig value chain were collected in the same way as the household coordinates. These locations included slaughter slabs (=informal, designated slaughter places with very limited possibility of ensuring biosecurity and hygiene), pork joints (=local restaurants that serve pork) as well as markets with pork kiosks selling fresh pork.

The questionnaire included a section with background information about the respondent's household and two interview sections. The first section (questions 1–12, see Supplementary material 1) included one open and ten closed and multiple-choice questions focusing on herd population dynamics; disease onset, outcome and clinical signs; actions taken during the outbreak; and perceived causes of the outbreak. For all closed and multiple-choice questions, the respondents also had the opportunity to freely add more information in an open comment. All included households were asked these questions. The second interview section (questions 13–17) included open questions on the impact of the outbreak. 31 of the households that had participated in a previous, ethnographic study were asked these questions. The results from the second interview section will be fully reported in a separate article, but some of these results were used in this study to facilitate interpreting responses to the first part of the survey and to enrich the description of the findings.

2.3. Laboratory analysis

Genomic DNA was extracted from blood and tissue samples using the DNeasy Blood and Tissue kit (Qiagen, Germany) following the manufacturer's instructions. For the blood samples, 100 µl of whole blood was used, resulting in a final eluate of 220 µls. Bones were split to expose the bone marrow for sampling. 25 mg of tissue was used from the muscle and bone marrow samples. The presence of extracted DNA was confirmed by running the samples on a 2 % agarose gel stained with ethidium bromide. Sequences were amplified in a 25 µls reaction volume using target primers to amplify the target virus sequence. A 278 bp region corresponding to the central portion of the p72 gene was targeted using primers PPA1–5'-AGTTATGGGAAACCCGACCC-3' and PPA2–5'-CCCTGAATCGGAGCATCCT-3'. 2 mls of the template DNA was added to 23 mls of the master mix to make 25 mls of final reaction volume. The cycling conditions were: initial denaturation at 95∘C for 10 min for 1 cycle; denaturation at 95∘C for 15 s; the annealing temperature was 55∘C for 30 s; the extension temperature was 72∘C for 30 s; the final extension temperature was 72∘C for 7 min; and the holding temperature was 40∘C. The denaturation, annealing and extension steps were repeated for 35 cycles. The PCR results were confirmed as positive or negative by running the samples on a 2 % agarose gel with the help of a positive control sample and a marker (DNA ladder).

2.4. Interview data handling and analysis

The time frame of the analysis covered the period from the day the onset of clinical signs was reported (defined as the start of the outbreak) to the day of the interview. A descriptive analysis of the quantitative interview data was performed using parametric and non-parametric statistical tests. For questions 11 and 13–17, qualitative interview data were extracted from the Excel sheet and a content analysis performed (White et al., 2006). Results from this analysis were used to illuminate the analysis of the quantitative results and deepen the understanding of the research questions.

The case definition used was that an ASF positive case was a household that reported pig deaths during the time under investigation. This definition was used in the ensuing analysis, classifying households as ASF positive or negative. To analyse the herd size dynamics, the herd sizes were divided into four categories according to the quartile ranges.

Next, we explored spatial clustering of the ASF positive households and the pig population in the study area. For this, we created a hexagonal grid with 1 kilometre (km) cell sides (each hexagon having an area of 2.6 square kilometres (km^2)). Then, we intersected the information within each hexagon, treating the household information (ASF positive or negative), the pig population, roads and the hexagon grid as spatial objects (Pebesma, 2018). We then calculated the densities and counts of pigs at the start of the outbreak and at the time of the interview as well as the difference between these two sums within each hexagon and plotted the result on a map (Venables and Ripley, 2013; Wickham et al., 2019). To improve visualisation, hexagons with zero counts were not plotted. Three types of risk location for ASF spread were plotted: main trading centres, small trading centres and slaughter slabs. Moreover, to detect and evaluate space-time clusters, we scanned a window across time (days) and the maximum spatial cluster size of 50 % of the pig population at risk and minimum temporal cluster size of five days in a discrete Poisson probability model of observed and expected cases (Kulldorff et al., 2005). In this model the space-time statistic is defined by a cylindrical window with a circular geographic base and with height corresponding to time with particular attention paid to any unusual excess. We used the pig population at risk at the start of the outbreak (using the same definition of this date as for the other analysis), the number of affected (dead or sick) pigs and the geographic location of the households (latitude and longitude) to set up a retrospective space-time permutation calculating the likelihood of each cylinder having more than its expected number of cases using using SaTScan (https://www.satscan.org). All data handling, statistical analysis and mapping were carried out using R v4.3.1 (R Core Team, 2023) running on RStudio (R Studio Team, 2020).

3. Results

In the initial outbreak investigation, six households in two villages were visited and 15 pigs sampled (13 blood samples, one muscle and one bone sample). All households visited had experienced pig deaths, with anamnestic stories being varied and ranging from piglet neonatal mortality to severe disease and deaths of several adult pigs. Both healthy and sick pigs had been sold and dead pigs were generally no longer available for sampling. In total, five blood samples from four households were positive for ASFV on PCR, confirming that ASF was circulating in affected households during the outbreak period. The samples from muscle and bone marrow respectively were both negative for ASFV on PCR.

Face-to-face interviews were conducted from 15th March to 24th July 2024, resulting in visits to 128 households and the collection of 57 variables of interest. The median time between the first detection of the disease in a certain household to the respective interview was 27 days (95 % confidence interval (CI): 3–144 days). The median age of respondents was 40 years (range: 18–75 years). Approximately half of the respondents were women (n = 63, 49 %). According to the case definition used, 61 households were ASF positive and 67 ASF negative (Fig. 1).

3.1. Pig population impact

The initial pig population in the study village comprised of 703 animals, which by the time of the interviews had been reduced to 527 animals (Table 1). Initially, the average number of pigs per household (herd size) was 5.25 (minimum (min)= 1, Q1 = 2, Q3 = 8, maximum (max)= 22) and herd size quartile ranges were 1–2 pigs in the first

Table 1
Description of the pig population from a study investigating an outbreak of African swine fever (ASF) in northern Uganda in 2024. The case definition used in the study was: ASF positive households=households that reported pig mortality during the time under investigation. N^0=number, pop.=population, ASF + =ASF positive household and ASF -= ASF negative household.

	House-holds (N°)	Total pig pop. at the start of the outbreak[a] (N°)	Total pig pop. at interview (N° (% reduction))	Average herd size at the start of the outbreak (N°)	Average herd size at inter-view (N°)	Morbidity (N° (%))	Mortality (N° (%))	Pigs sold (N° (% of initial pig pop.))
ASF+	61	349 [ns]	180 (48.42)**	5.72	3.05*	118 (33.81)*	140 (40.11)	33 (9.46)[ns]
ASF-	67	354	347 (1.98)	5.28	5.18	15 (4.24)	-	16 (4.52)
Total	128	703	527 (25.04)	5.49	4.12	133 (18.92)	140 (19.91)	49 (6.97)

*, **, ***, [ns]=The difference between the ASF positive and ASF negative households was statistically significant at levels: *$p < 0.1$, ** $p < 0.01$, *** $p < 0.001$ and ns= not significant.
[a] = As pig records are normally not kept in the study settings, the number of pigs might be an approximate appreciation by the respondent.

quartile, 3–4 pigs in the second quartile, 3–8 pigs in the third quartile and 9–22 pigs in the fourth quartile. At the time of the interviews, the average herd size had decreased by 25 % to 4.12 pigs (Table 1). When comparing the ASF positive and negative households' average herd size on the interview date using the Welch two-sample *t*-test, they were significantly different from each other (statistic −3.16) with a p-value of 0.002 (see Table 1). Before the outbreak, there was no significant difference in the average herd size in these two groups of households. By this time, 140 pigs had died, 33 had been sold and three slaughtered in the 61 ASF positive households, reducing the herd size by 48 % compared to a total reduction of 2 % (16 pigs) in the 67 ASF negative households. The mortality in the ASF positive households was 40 % (according to the case definition used, the mortality was zero in the ASF negative households), with morbidity of 34 % in positive households and 4 % in the negative households. The number of pigs sold alive was more than twice as high in positive households (9 %) compared to negative households (5 %) (Table 1).

In total, 39 households (30 %) ceased keeping pigs (at least temporarily) between the start of the outbreak and the interview. This led to a shift in the distribution of herd size categories based on the initial herd size quartiles, see Fig. 2. Among the 61 ASF positive households (Fig. 2A), 25 households (41 %) had ceased keeping pigs, while another 25 households had reduced their pig herd size by the time of the interview compared to the situation at the start of the outbreak. Out of the 61 ASF positive households, 11 households (18 %) maintained their original herd size. In contrast, out of the 67 ASF negative households (Fig. 2B), 57 households (85 %) retained their initial herd size, one household increased its herd size, one decreased its herd size and 14 households ceased production.

3.2. Pig practices and perceptions

When asked about what happened to the surviving pigs in the ASF positive households, the most common answer (n = 44, 64 %) was that these pigs were kept by the household. Three households (4 %) indicated that they had slaughtered their remaining pigs (accounting for four pigs). Additionally, nine households (13 %) reported that they had sold live pigs, accounting for 33 pigs in total (Table 2).

When asked about the disposal methods for the pigs that had died, 43 out of 89 responses to this question (48 %) mentioned selling the carcasses as the immediate action. 34 responses (38 %) indicated that the respondent households had consumed the dead animals, seven (8 %) that they had left the carcasses in the bush, one that a dead pig had been burned and one response mentioned that a carcass had been eaten by dogs. None of the households reported having buried deceased animals (Table 3).

When asked about the perceived cause of the pigs' illness, 43 out of

Table 2
Actions taken by households with pigs remaining in the herd after an outbreak of African swine fever from a study investigating an outbreak in northern Uganda in 2024.

Actions taken	Number of households (%)[a]	Number of pigs involved in the action (%)
Kept the pigs	44 (63.77)	159 (92.44)
Sold pigs alive	9 (13.04)	33 (5.23)
Slaughtered pigs	3 (4.35)	4 (2.33)
No response	13 (0)	-
Total	69 (100)	196 (100)

[a] Respondents could give several answers. The total number of households is thus more than the total number of African swine fever positive households.

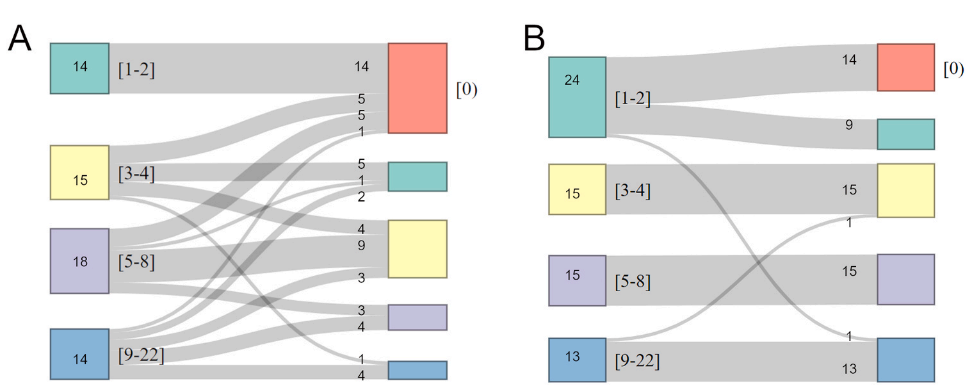

Fig. 2. A and 2B: Analysis of the herd size dynamics from a study investigating an outbreak of African swine fever (ASF) in northern Uganda in 2024. 2 A: ASF positive households, 2B: ASF negative households. Herd size quartile ranges is indicated in brackets with red indicating no pigs, green the first quartile range, yellow the second, purple the third, and blue the fourth quartile. The number of households in each quartile is indicated by the numbers inside the respective coloured squares. The grey paths represent how a households' herd size changed or remained in the same quartile between the start of the ASF outbreak and the interview. The numbers on the right side of the grey paths represent the number of households for each path. The case definition used in the study was: ASF positive households=households that reported pig mortality during the time under investigation.

Table 3
Actions taken with pigs that died during an outbreak of African swine fever in northern Uganda in 2024.

Actions taken	Number of households (%)[a,b]
Sold	43 (48.31)
Ate	34 (38.2)
Threw in the bush	7 (7.87)
Threw in the latrine	2 (2.25)
Burned	1 (1.12)
Buried	0
Other	2 (2.25)
Total	89 (100)

[a] We did not ask how many pigs were involved in these actions.
[b] Households could give several answers. The total number of responses is thus more than the total number of African swine fever positive households.

61 ASF positive households (71 %) identified a single cause and 11 households (18 %) cited multiple causes. Six households (8 %) mentioned that they did not know the cause. The most common perceived cause of the disease in these households (n = 28, 36 %) was related to the weather, with several mentions of high temperatures and sunshine. The second most frequent cause was contact with infectious pigs (n = 16, 21 %), followed by contaminated food intake and contact with people, both with six responses (8 %). The analysis of the open responses about perceived causes showed that these different causes were not seen as mutually exclusive. Common statements included appreciation that the disease is transmitted by a virus, but simultaneous acknowledgement that the disease mainly appears during hot weather. Respondents from the southern parts of the village, close to a national park, mentioned an association with the presence of elephants. This was not mentioned by participants from any other parts of the village. In total, three respondents specifically indicated ASF as the cause. None of the respondents attributed the deaths to witchcraft or jealousy, which were both included as multiple-choice options, as they have frequently been mentioned as explanations for pig deaths in previous interview studies in the village (Arvidsson et al., 2022b). Also, in the ASF negative households, contaminated food and weather conditions were among the most frequently mentioned causes of ASF (Table 4).

When asking the ASF positive households about their actions when their pigs were sick, the most common response was to give medicine to the animals (n = 17, 24 %). This was followed by tethering or fencing in the pigs (n = 13, 18 %), separating sick animals from healthy ones (n = 11, 16 %) and seeking help (n = 10, 14 %). Slaughtering sick pigs (n = 5, 7 %) and selling them while still alive (n = 4, 6 %) were also actions considered for dealing with sick animals (Table 5). None of the respondents reported praying or selling healthy pigs (both included in the multiple-choice options) as actions taken in relation to their sick pigs.

3.3. Temporal epidemiological distribution

The median interval between the reported onset of clinical signs and first death among pigs in the positive households was two days (95 %CI 0–4), confirming the acuteness of the disease. According to the results, the outbreak commenced in the second week of October 2023, reaching an epidemic peak in February 2024, followed by a decline by the end of March with a second epidemic wave occurring at the end of April and declining by mid-May (see Table 6 and Fig. 3). The highest weekly number of dead pigs (n = 30) and the highest number of affected households (n = 17) were recorded during the last week of February 2024. According to the data, during the first peak of the outbreak, the number of slaughtered pigs and the number of pigs sold alive remained constant whereas the number of pigs sold dead increased (Table 6). Likewise, no increase in the number of slaughtered pigs was observed during the second peak, but both the numbers of pigs sold alive and the number of pigs sold dead increased during this period.

Table 4
Causes associated with the pig illness from a study investigating an outbreak of African swine fever (ASF) in northern Uganda in 2024.

Causes	Number of responses from ASF positive households (%)[a],[b]	Number of responses from ASF negative households[a],[c]
Weather	28 (35.90)	4
Direct contact with sick pigs	16 (20.51)	0
Pig ate something	6 (7.69)	5
Contact with people	6 (7.69)	1
Elephant	4 (5.13)	0
ASF	3 (3.85)	0
Black fly	3 (3.85)	0
Poison	1 (1.28)	0
Someone killed the pig	1 (1.28)	0
Pig malaria	1 (1.28)	2
Don't know	6 (7.69)	2
Other	3 (3.85)	4
Total	81	18

[a] The case definition used in the study was: ASF positive households=households that reported pig mortality during the time under investigation.
[b] Households could give multiple answers or no answer. The total number of responses is thus not equal to the total number of ASF positive or negative households.
[c] This question was not asked of all ASF negative households. Therefore, a percentage is not calculated.

Table 5
Actions taken by the respondents when pigs were sick from a study investigating an outbreak of African swine fever (ASF) in northern Uganda in 2024.

Actions	Number of responses from ASF positive households (%)[a],[b]	Number of responses from ASF negative households (%)[a],[b],[c]
Gave medication	17 (23.9)	7
Tethered/fenced in the pigs	13 (18.3)	6
Separated sick from healthy pigs	11 (15.5)	1
Asked for help	10 (14.1)	1
Slaughtered sick pigs	5 (7.0)	0
Gave water	5 (7.0)	2
Sold alive	4 (5.6)	0
Other	6 (8.5)	3
Total	71	20

[a] The case definition used in the study was: ASF positive households=households that reported pig mortality during the time under investigation.
[b] Households could give multiple answers or no answer. The total is thus not equal to the total number of ASF positive or negative households.
[c] This question was not asked of all ASF negative households. Therefore, a percentage is not calculated.

3.4. Spatial epidemiological distribution

The study households were spatially dispersed across the village with many households located around two main trading centres, one in the north and one in the south of the village respectively, see Figs. 1 and 4. The main trading centre in the north included two slaughter slabs, two pork joints as well as markets and pork kiosks selling fresh pork. The main trading centre in the south included one slaughter slab, one pork joint, markets and pork kiosks. One additional slaughter slab and six

Table 6
Epidemiological data from a study investigating an outbreak of African swine fever (ASF) in northern Uganda in 2024. Weeks with a high (≥4) number (N°) of households (HH) becoming positive are marked in pink. Note that only weeks in which the data contained any information are represented in the table. Data in the columns to the right of the vertical black line concern the households (HH) that became positive during the week mentioned in the first column, but stretching over the entire study period (from disease detection to interview (i.e. not restricted to the week mentioned in the first column)).

Year: week of the year[1]	N° of HH becoming ASF positive[2]	Difference in pig N° [2,3]	N° of dead pigs	N° of pigs sold dead	N° of pigs sold alive	N° of slaughter-ed pigs
2023: 41	1	-8	3	1	5	0
44	1	-10	10	1	0	0
49	1	-4	4	1	0	0
51	1	-5	5	1	0	0
2024: 3	1	-2	2	0	0	0
5	1	-4	1	0	3	0
6	4	-15	13	1	2	0
7	3	-7	5	2	2	1
8	2	-8	8	2	0	0
9	17	-19	30	11	0	0
10	6	-10	11	6	1	2
11	6	-9	7	1	2	0
12	2	-8	6	1	2	0
13	1	-1	1	1	0	0
14	3	-4	4	1	0	0
15	1	-2	2	1	0	0
16	2	-2	2	1	0	0
17	1	-18	5	1	13	0
18	4	-13	10	4	3	0
20	1	-8	8	0	0	0
25	1	-11	2	1	0	0
27	1	-1	1	1	0	0
Total	61	-169	140	38	33	3

[a] Households were assigned to the respective week according to the first day of the reported onset of clinical signs.
[b] The case definition used in the study was: ASF positive households=households that reported pig mortality during the time under investigation.
[c] The difference between the number of pigs at the time of the interview compared to the number of pigs at the start of the outbreak.

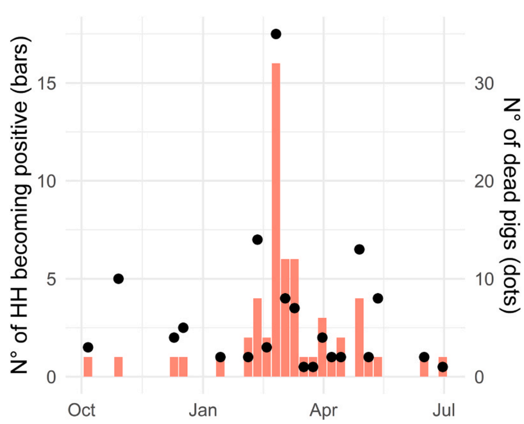

Fig. 3. Number (N^0) of positive households (HH) and number of dead pigs from a study investigating an outbreak of African swine fever (ASF) in northern Uganda in 2024. The bars represent the number of households becoming positive per week as marked on the x-axis. The black dots represent the number of dead pigs in the corresponding HHs according to the secondary scale on the right. The number of dead pigs cover the entire study period, from disease detection to interview (i.e. not only during the time marked on the x-axis). The case definition used in the study was: ASF positive households=households that reported pig mortality during the time under investigation.

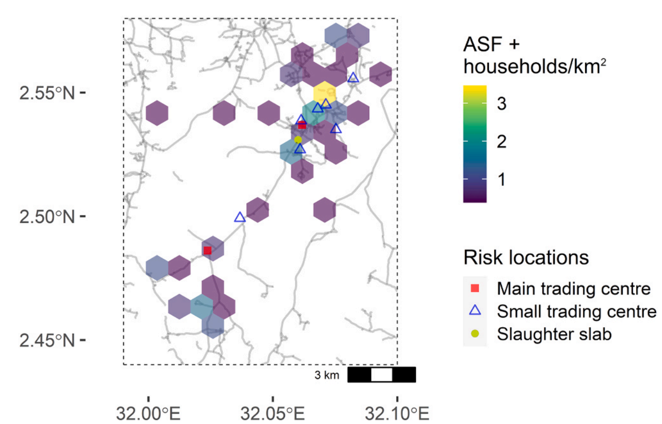

Fig. 4. Density of African swine fever positive households (ASF +) from a study investigating an outbreak of ASF in northern Uganda in 2024. Roads are displayed in grey and number of ASF + households per square kilometre (km^2) according to a colour gradient grouped on a hexagonal grid with 1 km cell sides. The case definition used in the study was: ASF positive households=households that pig mortality during the time under investigation.

smaller trading centres were located across the study village, see Fig. 4. The highest density of ASF positive households per km^2 (3.5) was found in a hexagon in close vicinity to three small trading centres and the northern main trading centre. Additional hotspot areas (> 1 ASF positive household per km^2) were identified in the vicinity of the southern and northern main trading centres respectively as well as close to a small trading centre located halfway between the two main trading centres (see Fig. 4).

The spatial distribution of the pig populations at the start of the outbreak and at the time of the interview, respectively, can be seen in Fig. 5A and B. Higher pig densities were observed around the northern main trading centre, close to a small trading centre between the northern and southern main trading centres and in the southernmost parts of the village. In Fig. 5C, the difference in the size of the pig population between the start of the outbreak and the time of the interview can be seen, for example, with all pigs disappearing in some hexagons and some hexagons increasing their pig population (min=plus 3.0769 pigs, median=minus 0.77 pigs, max=minus 8.08 pigs). Out of 43 hexagons analysed, two (marked in yellow and light orange) showed an increase in pig population between the two time points. Meanwhile, 19 hexagons maintained their population levels (orange) and 22 hexagons (dark orange, purple and black) showed a reduction in pig population ranging from minus one to minus eight pigs per km^2 (Fig. 5C). In general, the reduction in pig population was higher in hexagons with high initial pig population, with many ASF positive households and in the northern part of the village. Four hexagons in the northern part of the village that showed the highest initial pig population density and high reduction of their pig population formed a corridor along the main road. There were a few hexagons without any ASF positive households but that still showed a reduction in their pig population.

3.5. *Spatiotemporal epidemiological distribution*

The retrospective space-time analysis included all 128 households with a total population of 703 animals and detected two significant clusters among the 61 positive households. The northern cluster (cluster A, see Fig. 6) spanned 2.8 km^2 and included 66 households with an initial population of 307 pigs. This cluster's time frame was 37 days between 11th February and 19th March 2024. 32 households became ASF positive during the time frame. The southern cluster (cluster B, see Fig. 6) covered an area of 4.2 km^2 with 28 households and an initial population of 177 pigs. The time frame for this cluster was 5 days between 25th and 29th February 2024. 14 households became ASF-positive during this time frame. The larger area of the southern cluster reflects a more dispersed population, lower population at risk and lower mortality because of the short time the cluster was present. Both clusters showed high likelihood ratios, indicating that the observed cases were

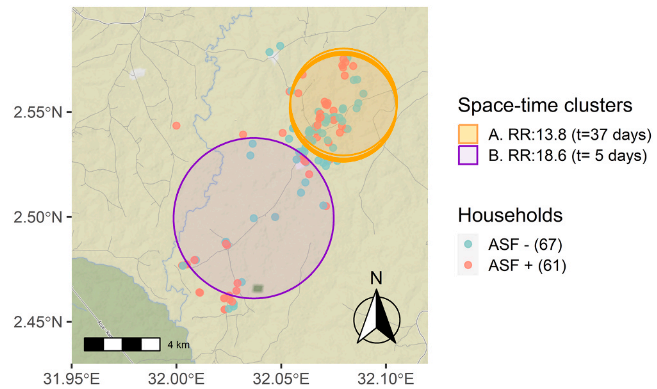

Fig. 6. Location of detected retrospective space-time clusters in a study investigating an outbreak of African swine fever (ASF) in northern Uganda in 2024. ASF positive households are marked with red dots and negative households with green dots. Cluster A is marked with orange, big cylinders and Cluster B with purple, big cylinders. RR= relative risk, t = time span of the cluster. The case definition used in the study was: ASF positive households=households that reported pig mortality during the time under investigation.

not due to random chance with associated p-value < 0.001. See Fig. 6 and Table 7.

4. Discussion

This study offered a rare opportunity to analyse local ASF epidemiology in a resource-constrained smallholder setting in close temporal connection to an outbreak. Important knowledge was gained regarding the spatial and temporal distribution of ASF, risk locations for ASF spread connected to activities in the value chain, disease impact as well as how local people perceive and act upon an ASF outbreak. Such insights are needed to deepen the understanding of ASF in the smallholder pig value chain, where the majority of ASF spread occurs in most parts of the world (Penrith et al., 2021). Detailed and locally grounded knowledge on these topics is further needed to design and deliver biosecurity advice fitting to reduce the spread of ASF in similar settings and to ensure that advice is well adapted to smallholders' daily realities. The importance of the latter has received more attention recently, with previous advice often proposing measures that are unrealistic in low-income settings (FAO, 2023; Penrith et al., 2023). As an example, the safe disposal of carcasses is a very important measure for preventing

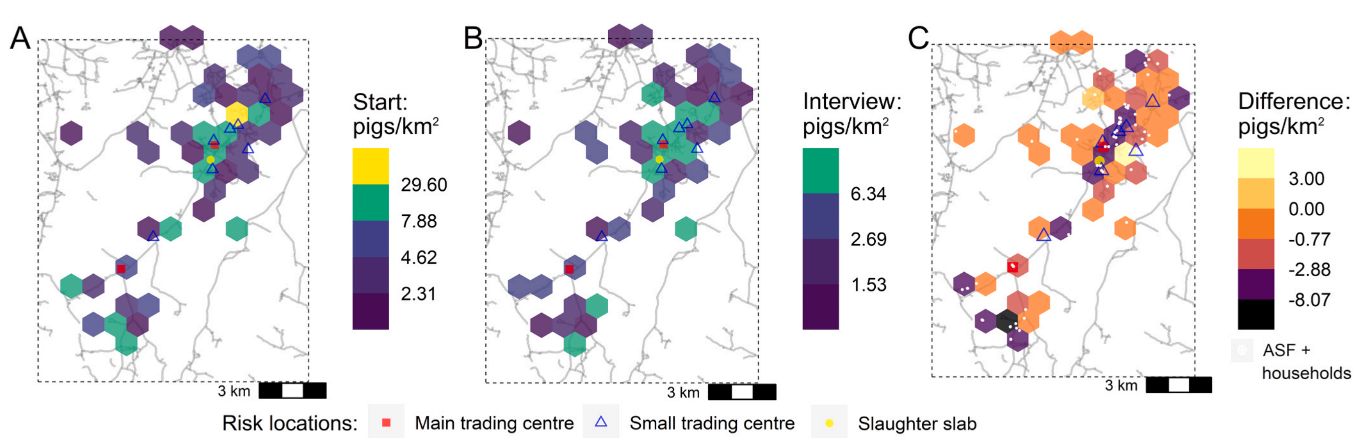

Fig. 5. A, 5B and 5 C: Analysis of the density of the pig population from a study investigating an outbreak of African swine fever (ASF) in northern Uganda in 2024. 5 A: Number of pigs/square kilometre (km^2) at the start of the outbreak. 5B: Number of pigs/km^2 at the time of the interview. 5 C: The difference in number of pigs/km^2 between the two time points displayed in 5 A and 5B. Pig population/km^2 and the difference in pig population/km^2 is showed as colour scales on a hexagonal grid with 1 km cell sides. In 5 C ASF positive households are marked as white dots. The case definition used in the study was: ASF positive households=households that reported pig mortality during the time under investigation.

Table 7
Description of the significant clusters detected from a retrospective space-time analysis in a study investigating an outbreak of African swine fever in northern Uganda in 2024. ASF + =ASF positive. The case definition used in the study was: ASF positive households=households that reported pig mortality during the time under investigation.

Cluster details	Cluster A	Cluster B
Centre coordinates	2.578 N, 32.044 E	2.499 N, 32.036 E
Radius	2.8 km	4.21 km
Time frame	11–02–2024 to 19–03–2024	25–02–2024 to 29–02–2024
Initial pig population number	307	177
Total/ASF + households	66/32	28/14
Number of dead pigs	*62*	10
Expected number of dead pigs	7.62	0.58
Observed/expected dead pigs	8.14	17.31
Relative risk	13.81	18.56
Log likelihood ratio	88.73	19.41
p-value	< 0.001	< 0.001

ASF spread during outbreaks and burning or deep burial is frequently recommended (Nantima et al., 2016). According to the results, burying a dead animal is not practised in the study area. This finding confirms previous research in which a social taboo connected to burying animals other than humans, the physical effort needed to dig a grave and costs for fuel to burn carcasses are described as hindering the implementation of these measures (Mutua et al., 2017; Chenais et al., 2023a). Other safe disposal methods, such as disposing of the carcass in a latrine, were not used by the respondents in this study either. The majority of respondents in this study instead stated that they had disposed of dead pigs in ways that could contribute to ASF spread, like selling dead pigs or throwing carcasses in the bush or to the dogs. Consuming pork from a pig that has died from ASF, which was common according to the results, is indeed a safe way to dispose of the parts that are consumed, but the inedible parts will still need to be disposed of safely in order not to contribute to the risk of spreading ASF. Consuming pigs that have died from disease may constitute a public health concern, but, in the study setting, wasting high value protein is often considered a more direct health threat and throwing away meat has been mentioned as being taboo (Coffin et al., 2015; Chenais et al., 2023a; Chenais et al., 2023b).

According to previous research, the slaughter and sale of in-contact, sick and even dead pigs are common ways for smallholders to deal with the challenges of ASF outbreaks in low-income settings, frequently described as “panic sales” (Dione et al., 2016; Fasina et al., 2020; Aliro et al., 2022). In this study, however, the slaughter or sale of live pigs (in-contact pigs/pigs remaining in the herd after the outbreak) and sick pigs (Tables 2, 5 and 6) was not reported as common. On the other hand, selling was the most common action taken with the pigs that had died, followed by consumption of the carcass as the second most common. Selling the carcass of a dead pig and eating the carcass are actions that conform to expected human behaviour in this context. In times of crisis, resource-constrained smallholders are frequently reported to prioritise actions that support livelihoods and family nutrition. More research would be needed to fully understand why smallholders in ASF affected households reportedly rarely sold live pigs, as this has been commonly reported in other similar contexts. Here, we elaborate on some more and less likely reasons for this finding. One expected reason as to why ASF affected households reported not selling live pigs would be that this is not socially accepted and, therefore, not done; alternatively, the fact that it is not socially accepted and, therefore, might be done but not reported to us is another reason (Paulhus, 1991). Indeed, strong social control and peer pressure have been found to act both as an enabler and a barrier to biosecurity in similar settings (De Vries et al., 2016). We, however, find this explanation less plausible in the present case for two reasons. Firstly, smallholders seem to be aware that both dead and alive pigs can transmit ASF and, therefore, it is unlikely that it would be acceptable to sell pigs that have died from ASF and not live pigs from ASF infected households. Secondly, we believe it to be unlikely that smallholders would have withheld information, to any significant extent, about selling live pigs, both because they reported performing other actions that many local residents know contribute to disease spread (including selling pigs that have died from disease) and because of our study design. Regarding our study design, the interviews were conducted in a village where we have worked for many years and established confidence with the local residents. Additionally, the author who conducted the interviews (AO) is a trusted local resident and, most importantly, has no formal or informal authority in the village, no government connections and is not a veterinarian. In these kinds of studies, it is otherwise common that data are collected by local veterinarians. As veterinarians are often seen as an authority on animal health and as an extended arm of the government, respondents are likely to be reluctant to report on actions that they know are incorrect or negative from an animal health point of view (Elbers et al., 2010; de Balogh et al., 2013). We believe that the study design used with the questionnaire survey implemented by a local resident trusted by his peers, who has no formal training in veterinary medicine, reduced the potential for this kind of bias to occur (Paulhus, 1991). Based on our understanding of the local context, we conclude that a more likely reason that smallholders sold pigs that had died from ASF but not live pigs with symptoms was that they hoped that they would be able to cure the pigs that were still alive.

The most common response to what actions were taken as the pigs fell sick was to give medication. We did not enquire as to what kinds of medication. Still, these responses could highlight several issues: either that ASF was not recognised and the respondents thought the pigs were suffering from another disease that could be cured by medication or a misconception that ASF can be cured. In previous studies in the same community, respondents expressed that they thought prevention/cure for ASF did indeed exist, but that it was not accessible to them as poor farmers in remote, rural Uganda (Arvidsson et al., 2023). Only ten of the 61 ASF positive households responded that they asked for help, which might be an outcome of the significant lack of access to veterinary health care in this area of Uganda (Ilukor et al., 2013; Arvidsson et al., 2022a).

Previous research from the study village reported that smallholders are less knowledgeable about pig management and pig health than about other livestock (Arvidsson et al., 2023). Interviews conducted in the study village directly preceding this study (as yet unpublished) indicate that this has changed since the 2023 publication. Smallholders were now generally more knowledgeable about pig rearing and how to ensure general pig health and wellbeing than in 2023. This is also confirmed by the open answers to the survey questions, which indicated a widespread understanding that ASF spreads between pigs and that confinement is an important preventive measure. While the present results might seem to contradict the presence of increased knowledge about ASF, for example, as “weather” was the most commonly reported reason for the pigs succumbing to ASF, the open answers make clear that a large share of smallholders simultaneously agree with the current scientific knowledge that direct and indirect contact is an important route of disease spread. This mix of local and scientific knowledge is frequently reported from settings with more limited access to modern medicine and advice and from people with limited formal education, where people are used to relying on local solutions and associated explanatory models, but also for whom a virus might remain a difficult subject to grasp (Chenais and Fischer, 2018; Fischer et al., 2020; Tasker, 2020; Arvidsson et al., 2023). Elephants were mentioned as a reason for the pig deaths exclusively from participants in the southern parts of the study village located close to an un-fenced national park with a large elephant population. This might be an example of how a local explanatory model is created based on what can be observed and experienced, but might also likely be an outcome of respondents taking the opportunity to visualise their problem with elephants (elephants frequently damage crops and even infrastructure and are, therefore, viewed negatively by residents living close to parks) (Tschakert et al., 2016; Muthiru et al., 2024).

It is well known that in most parts of the world, currently and historically, the domestic pig epidemiological cycle is the dominating mode of ASF virus transmission (Costard et al., 2009; Penrith and Vosloo, 2009; Penrith, 2020). Furthermore, in this cycle, most spread occurs during the daily activities of the stakeholders along the value chain (Penrith et al., 2019). As the blood of viraemic pigs contains high viral loads (Gallardo et al., 2017), unsafe slaughtering remains a high-risk activity for ASF spread (Viltrop et al., 2021). In Uganda, as in many sub-Saharan countries with endemic ASF occurrence, pig slaughter is largely informal and happens at so-called slaughter slabs with no or very few opportunities to perform bio-safe slaughter (FAO, 2023). For example, the bleeding of pigs might take place on a surface without drainage with offal left at the side of the site. The proximity to live pig markets and slaughter slabs has previously been associated with a higher risk of ASF outbreaks (Lichoti et al., 2017; Adedeji et al., 2022; Fasina et al., 2024). This also seems to be the case in this study, with the spatial analysis showing outbreak hot spots in close spatial connection to trading centres and slaughter slabs.

Animal diseases with high mortality, such as ASF, are frequently found to impact poor farmers (i.e. those with small herds) more than comparatively wealthier farmers (i.e. those with larger herds) (Bett et al., 2009; Perry and Grace, 2009). For a poor family owning only one or a few animals, the death of this animal might be a substantial livelihood shock (Rich and Perry, 2011). Livelihood impacts from animal disease and death in low-income settings are, furthermore, much wider than the economic impact and difficult to quantify (Perry et al., 2002; Grace et al., 2017). Even if only including the economic impact, animal health economics studies in smallholder settings are complex (Rich et al., 2005). Previous research by the authors in a similar setting, however, shows that, due to the generally low inputs invested in pig management, the direct economic loss from a dead pig might be relatively small, but the loss of future, expected income might still be substantial (Chenais et al., 2017). In the study by Chenais et al. (2017), increasing herd size was associated with a higher economic impact from ASF outbreaks. In the present study, the impact measured as a reduction in the pig population was spatially dispersed with a higher relative reduction in areas with higher initial pig population density. As most pigs in the study village are kept free range, a higher pig population density naturally leads to more frequent direct pig contacts and, thus, opportunities for virus transmission. In this study, the pig population in an ASF positive household was reduced by almost half during the outbreak despite a relatively low pig population density. The spatial analysis suggests associations between pig population density at the start of the outbreak, risk locations for ASF spread, ASF occurrence on a household level and impact in the form of a reduction in pig population. The size and direction of these associations could not be determined in the present study and other risk factors embedded in the local context not studied here could act as confounding variables. As an example of the associations and their spatial interconnectedness, the four hexagons in the northern part of the village that form a corridor along the main road have high initial pig density, a high number of ASF positive households, a high reduction in pig population and the presence of risk locations for ASF spread. The presence of hexagons without any ASF positive household but with a reduction in pig population suggests a wider impact on the pig population than the immediate disease effects in the form of mortality.

This study had some limitations. It is noted how difficult it is to get good, representative tissue samples from pigs suspected of being infected with ASF in a resource-constrained smallholder context. Despite the researchers' good connections in the study village and two of the authors (TA and AO) residing in the area, there was a delay of several months from the start of the outbreak to reports of pig deaths reaching us. This meant that the peak outbreak had passed by the time the initial outbreak was being investigated and it was difficult to find relevant pigs to sample. Therefore, after having confirmed the presence of ASFV in the area by PCR, a case description including pig mortality was applied and no more biological sampling and testing undertaken. Pigs could have died of causes other than ASF during the study time, leading to false positive households in the analysis and, consequently, for example, exaggerating the decrease in pig population due to ASF compared to a decrease due to other reasons. Considering the correlation between the temporally and spatially clustered occurrence of the pig deaths and the laboratory confirmed cases, as well as previous studies strongly suggesting ASF to be the most common cause of epidemic outbreaks with high case fatality rates in pigs in the area and in the country (Muhangi et al., 2015), the likelihood of the case definition indicating true positive households is, however, estimated as high. Another limitation of the study was that our time and resources for data collection did not allow for all households in the village to be interviewed. As a result, we only have data from pig-keeping households and, relatedly, only data on pig population density and not human population density. As human actions are important drivers of ASF spread, data on human population density would have added important information that would have enriched the epidemiological analysis. Further, pig records are seldom kept in the pig husbandry and context dominating our study setting. It is, therefore, possible that the number of pigs given as responses to the quantitative questions could be wrong. It is not foreseen, however, that this reporting bias would differ between ASF positive and negative households and, hence, that it would affect the results.

In conclusion, this study revealed high impact in the form of pig mortalities and, consequently, reduction of the total pig population and household herd sizes. Indirect household consequences of the measured outbreak impact were not studied, but, based on previous knowledge, the hypothetical cash value of pigs and the already constrained resources in the community mean that it can be assumed that substantial negative social and economic consequences were experienced in many of the affected households. The temporal and spatial clustering and interconnectedness of ASF positive households as well as the distribution of the reduction in pig population and the risk locations for ASF spread confirm the important role of people, their actions and behaviour in the epidemiology of ASF in the domestic pig epidemiological cycle in this and similar smallholder contexts. Examples of reported outbreak responses, such as selling dead pigs and the unsafe disposal of carcasses, highlight the importance of resource constraints and the need to prioritise family livelihoods as disease drivers in low-income settings. The results also suggest that, in order to reduce ASF spread in this and similar settings, more attention needs to be paid to smallholders' access to veterinary health and extension services alongside how these services and their contents are adapted to the local context.

CRediT authorship contribution statement

Alfredo Acosta: Writing – original draft, Visualization, Formal analysis, Data curation. **Erika Chenais:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Data curation, Conceptualization. **Alfred Ojok:** Investigation. **Tonny Aliro:** Investigation. **Klara Fischer:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Karl Ståhl:** Writing – review & editing, Funding acquisition, Conceptualization.

Authors contribution

EC, KF and KS designed the study. TA and AO performed the field work. AA performed the statistical analysis and summarised the results of this analysis in writing, EC compiled a first draft of the manuscript, all authors contributed to the analysis and the finalisation of the manuscript.

Ethical conisderations and research permits

This study was reviewed and approved by Makerere University, College of Health Sciences (ref 2019–062). Oral informed consent was assured by all respondents in the study. All individuals are anonymised.

In addition, the District Veterinary Office, under the Ministry of Agriculture, Animal Industry and Fisheries has the official mandate to carry out investigations to animal disease in Uganda. Such investigations can include various methods of information collection such as sampling of animals and interviews with animal owners. All investigations in the field were performed in cooperation with the District Veterinary Office in Gulu/Nwoya, and the results communicated accordingly.

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Declaration of Competing Interest

The authors declare no conflicts of interests.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.prevetmed.2025.106601.

Data availability

All data is available from the first author upon reasonable request.

References

Adedeji, A.J., Atai, R.B., Gyang, H.E., Gambo, P., Habib, M.A., Weka, R., Muwanika, V.B., Masembe, C., Luka, P.D., 2022. Live pig markets are hotspots for spread of African swine fever virus in Nigeria. Transbound. Emerg. Dis. 69, e1526–e1540.

Aliro, T., Chenais, E., Odongo, W., Okello, D.M., Masembe, C., Ståhl, K., 2022. Prevention and control of African swine fever in the smallholder pig value chain in Northern Uganda: thematic analysis of stakeholders' perceptions. Front. Vet. Sci. 1586.

Ampaire, A., Rothschild, M., 2010. Pigs goats chickens rural development small holder farmer's experience Uganda.

Arvidsson, A., Fischer, K., Chenais, E., Kiguli, J., Sternberg-Lewerin, S., Ståhl, K., 2023. Limitations and opportunities of smallholders' practical knowledge when dealing with pig health issues in northern Uganda. PLoS One 18, e0287041.

Arvidsson, A., Fischer, K., Hansen, K., Sternberg-Lewerin, S., Chenais, E., 2022a. Diverging discourses: animal health challenges and veterinary care in northern Uganda. Front. Vet. Sci. 9.

Arvidsson, A., Fischer, K., Hansken, K., Kiguli, J., 2022b. Pigs as a shortcut to money? Social traps in smallholder pig production in northern Uganda. J. Rural Stud. 94, 319–325.

Bendali, F., 2006. La conception et la mise en oeuvre de programmes d′épidémiosurveillance efficaces dans les pays d′Afrique subsaharienne. Rev. Sci. Et. Tech. Off. Int. Des. épizooties 25, 199–209.

Bett, B., Jost, C., Allport, R., Mariner, J., 2009. Using participatory epidemiological techniques to estimate the relative incidence and impact on livelihoods of livestock diseases amongst nomadic pastoralists in Turkana South District, Kenya. Prev. Vet. Med 90, 194–203.

Branch, A., 2013. Gulu in war… and peace? The town as camp in northern Uganda. Urban Stud. 50, 3152–3167.

Chenais, E., 2017. African swine fever in Uganda. Department of Biomedical Sciences and Veterinary Public Health,. Swedish University of Agricultural Sciences, Uppsala.

Chenais, E., Boqvist, S., Emanuelson, U., von Bromssen, C., Ouma, E., Aliro, T., Masembe, C., Stahl, K., Sternberg-Lewerin, S., 2017. Quantitative assessment of social and economic impact of African swine fever outbreaks in northern Uganda. Prev. Vet. Med 144, 134–148.

Chenais, E., Fischer, K., 2018. Increasing the local relevance of epidemiological research: situated knowledge of cattle disease among basongora pastoralists in Uganda. Front. Vet. Sci. 5, 119.

Chenais, E., Fischer, K., Aliro, T., Ståhl, K., Lewerin, S.S., 2023a. Co-created community contracts support biosecurity changes in a region where African swine fever is endemic–Part II: implementation of biosecurity measures. Prev. Vet. Med., 105902

Chenais, E., Sternberg-Lewerin, S., Aliro, T., Ståhl, K., Fischer, K., 2023b. Co-created community contracts support biosecurity changes in a region where African swine fever is endemic – Part I: the methodology. Prev. Vet. Med. 212, 105840.

Chenais, E., Sternberg-Lewerin, S., Boqvist, S., Emanuelson, U., Aliro, T., Tejler, E., Cocca, G., Masembe, C., Ståhl, K., 2015. African swine fever in Uganda: qualitative evaluation of three surveillance methods with implications for other resource-poor settings. Front. Vet. Sci. 2, 51.

Coffin, J.L., Monje, F., Asiimwe-Karimu, G., Amuguni, H.J., Odoch, T., 2015. A One Health, participatory epidemiology assessment of anthrax (Bacillus anthracis) management in Western Uganda. Soc. Sci. Med. 129, 44–50.

Costard, S., Wieland, B., de Glanville, W., Jori, F., Rowlands, R., Vosloo, W., Roger, F., Pfeiffer, D.U., Dixon, L.K., 2009. African swine fever: how can global spread be prevented? Philos. Trans. R. Soc. Lond. B Biol. Sci. 364, 2683–2696.

de Balogh, K., Halliday, J., Lubroth, J., 2013. Integrating the surveillance of animal health, foodborne pathogens and foodborne diseases in developing and in-transition countries. Rev. Sci. Tech. 32, 539–548.

De Vries, D.H., Rwemisisi, J.T., Musinguzi, L.K., Muhangi, T.E., De Groot, M., Pool, R., 2016. The first mile: community experience of outbreak control during an Ebola outbreak in Luwero District, Uganda. BMC public health 16, 1–12.

Dione, M., Ouma, E., Opio, F., Kawuma, B., Pezo, D., 2016. Qualitative analysis of the risks and practices associated with the spread of African swine fever within the smallholder pig value chains in Uganda. Prev. Vet. Med. 135, 102–112.

Elbers, A., Gorgievski, M., Zarafshani, K., Koch, G., 2010. To report or not to report: a psychosocial investigation aimed at improving early detection of avian influenza outbreaks. OIE. Rev. Sci. Et. Tech. 29, 435–449.

FAO, 2023. African swine fever prevention, detection and control in resource-limited settings. FAO Animal Production and Health Guidelines. FAO, Rome.

Fasina, F.O., Kissinga, H., Mlowe, F., Mshang'a, S., Matogo, B., Mrema, A., Mhagama, A., Makungu, S., Mtui-Malamsha, N., Sallu, R., 2020. Drivers, risk factors and dynamics of African swine fever outbreaks, southern highlands, Tanzania. Pathogens 9, 155.

Fasina, F.O., Mtui-Malamsha, N., Nonga, H.E., Ranga, S., Sambu, R.M., Majaliwa, J., Kamani, E., Okuthe, S., Kivaria, F., Bebay, C., 2024. Semiquantitative risk evaluation reveals drivers of african swine fever virus transmission in smallholder pig farms and gaps in biosecurity, Tanzania. Vet. Med. Int. 2024, 4929141.

Fischer, K., Schulz, K., Chenais, E., 2020. Can we agree on that"? Plurality, power and language in participatory research. Prev. Vet. Med 180, 104991.

Gallardo, C., Soler, A., Nieto, R., Cano, C., Pelayo, V., Sanchez, M.A., Pridotkas, G., Fernandez-Pinero, J., Briones, V., Arias, M., 2017. Experimental infection of domestic pigs with african swine fever virus Lithuania 2014 Genotype II Field Isolate. Transbound. Emerg. Dis. 64, 300–304.

Grace, D., Lindahl, J., Wanyoike, F., Bett, B., Randolph, T., Rich, K.M., 2017. Poor livestock keepers: ecosystem-poverty–health interactions. Philos. Trans. R. Soc. B Biol. Sci. 372, 20160166.

Ilukor, J., Birner, R., Rwamigisa, P.B., Nantima, N., 2015. The provision of veterinary services: who are the influential actors and what are the governance challenges? A case study of Uganda. Exp. Agric. 51, 408–434.

Ilukor, J., Birner, R., Rwamigisa, P., Nantima, N., 2013. Analysis of veterinary service delivery in Uganda: an application of the Process Net-Map Tool. Hohenheim and Kampala: University of Hohenheim, Institute of Agricultural Economics and Social Sciences in the Tropics and Subtropics, Germany, and Ministry of Agriculture Animal Industry and Fisheries Department of Livestock Health and Entomology.[Google Scholar].

Kukielka, E.A., Jori, F., Martínez-López, B., Chenais, E., Masembe, C., Chavernac, D., Ståhl, K., 2016. Wild and domestic pig interactions at the wildlife–livestock interface of Murchison Falls national Park, Uganda, and the potential association with African swine fever outbreaks. Front. Vet. Sci. 3, 31.

Kulldorff, M., Heffernan, R., Hartman, J., Assunçao, R., Mostashari, F., 2005. A space–time permutation scan statistic for disease outbreak detection. PLoS Med. 2, e59.

Lichoti, J.K., Davies, J., Maru, Y., Kitala, P.M., Githigia, S.M., Okoth, E., Bukachi, S.A., Okuthe, S., Bishop, R.P., 2017. Pig traders' networks on the Kenya-Uganda border highlight potential for mitigation of African swine fever virus transmission and improved ASF disease risk management. Prev. Vet. Med 140, 87–96.

Muhangi, D., Masembe, C., Emanuelson, U., Boqvist, S., Mayega, L., Ademun, R.O., Bishop, R.P., Ocaido, M., Berg, M., Ståhl, K., 2015. A longitudinal survey of African swine fever in Uganda reveals high apparent disease incidence rates in domestic pigs, but absence of detectable persistent virus infections in blood and serum. BMC Vet. Res. 11, 1–11.

Mulumba-Mfumu, L.K., Saegerman, C., Dixon, L.K., Madimba, K.C., Kazadi, E., Mukalakata, N.T., Oura, C.A., Chenais, E., Masembe, C., Ståhl, K., 2019. African swine fever: update on Eastern, Central and Southern Africa. Transbound. Emerg. Dis. 66 14621480.

Muthiru, A.W., Muema, J., Mutono, N., Thumbi, S., Bukachi, S.A., 2024. Explanatory models and animal health-seeking behavior for East Coast fever in rural Kenya: an ethnographic study. Front. Vet. Sci. 11, 1400467.

Mutua, E.N., Bukachi, S.A., Bett, B.K., Estambale, B.A., Nyamongo, I.K., 2017. We do not bury dead livestock like human beings: community behaviors and risk of Rift Valley Fever virus infection in Baringo County, Kenya. PLoS Negl. Trop. Dis. 11, e0005582.

Nantima, N., Davies, J., Dione, M., Ocaido, M., Okoth, E., Mugisha, A., Bishop, R., 2016. Enhancing knowledge and awareness of biosecurity practices for control of African swine fever among smallholder pig farmers in four districts along the Kenya–Uganda border. Trop. Anim. Health Prod. 48, 727–734.

Nantima, N., Ocaido, M., Ouma, E., Davies, J., Dione, M., Okoth, E., Mugisha, A., Bishop, R., 2015. Risk factors associated with occurrence of African swine fever outbreaks in smallholder pig farms in four districts along the Uganda-Kenya border. Trop. Anim. Health Prod. 47, 589–595.

Ouma, E., Dione, M., Lule, P., Rosel, K., Pezo, D., 2013. Characterization of smallholder pig production systems in Uganda: constraints and opportunities for engaging with market systems. Agric. Vet. Sci. 1084.

Paulhus, D.L., 1991. Measurement and control of response bias.

Payne, A., Ogweng, P., Ståhl, K., Masembe, C., Jori, F., 2021. Spatial-temporal movements of free ranging pigs at the wildlife-livestock interface of Murchison Falls National Park, Uganda: potential of disease control at a local scale. Front. Vet. Sci. 930.

Pebesma, E., 2018. Simple features for R: standardized support for spatial vector data.

Penrith, M.L., 2020. Current status of African swine fever. CABI Agric. Biosci. 1 126.

Penrith, M.L., Bastos, A.D., Etter, E.M., Beltrán-Alcrudo, D., 2019. Epidemiology of African swine fever in Africa today: sylvatic cycle versus socio-economic imperatives. Transbound. Emerg. Dis. 66, 672–686.

Penrith, M.-L., Kivaria, F.M., Masembe, C., 2021. One hundred years of African swine fever: a tribute to R. Eustace Montgomery. Transbound. Emerg. Dis.

Penrith, M.-L., van Heerden, J., Pfeiffer, D.U., Oļševskis, E., Depner, K., Chenais, E., 2023. Innovative research offers new hope for managing African swine fever better in resource-limited smallholder farming settings: a timely update. Pathogens 12, 355.

Penrith, M.L., Vosloo, W., 2009. Review of African swine fever: transmission, spread and control. J. S Afr. Vet. Assoc.

Penrith, M.L., Vosloo, W., Jori, F., Bastos, A.D.S., 2013. African swine fever virus eradication in Africa. Virus Res 173, 228–246.

Perry, B., Grace, D., 2009. The impacts of livestock diseases and their control on growth and development processes that are pro-poor. Philos. Trans. R. Soc. Lond. B Biol. Sci. 364, 2643–2655.

Perry, B.D., Randolph, T.F., McDermott, J.J., K.R, S, P.K., T, 2002. Investing in Animal Health Research to Alleviate Poverty. International Livestock Research Institute Nairobi, Kenya.

Plowright, W., 1981. African swine fever. Infectious Diseases of Wild Mammals. Iowa State University Press Ames.

R Core Team, 2023. A Language and Environment for Statistical Computing.

Rich, K.M., Perry, B.D., 2011. The economic and poverty impacts of animal diseases in developing countries: new roles, new demands for economics and epidemiology. Prev. Vet. Med 101, 133–147.

Rich, K., Winter-Nelson, A., Miller, G., 2005. Enhancing economic models for the analysis of animal disease. Rev. Sci. Et. Tech. (Int. Off. Epizoot.) 24, 847–856.

RStudio Team, 2020. RStudio: Integrated Development Environment for R. RStudio. PBC, Boston, MA.

Tasker, A., 2020. Exploring power and participation through informal livestock knowledge networks. Prev. Vet. Med, 105058.

Tourangeau, R., 1999. Remembering what happened: Memory errors and survey reports. The science of self-report: Implications for research and practice. Psychology Press, New York, pp. 41–60.

Tschakert, P., Ricciardi, V., Smithwick, E., Machado, M., Ferring, D., Hausermann, H., Bug, L., 2016. Situated knowledge of pathogenic landscapes in Ghana: understanding the emergence of Buruli ulcer through qualitative analysis. Soc. Sci. Med. 150, 160–171.

UBOS, 2020. 2020 Statistical abstract. Uganda Bureau of Statistics.

Venables, W.N., Ripley, B.D., 2013. Modern applied statistics with S-PLUS. Springer Science & Business Media.

Viltrop, A., Boinas, F., Depner, K., Jori, F., Kolbasov, D., Laddomada, A., Stahl, K., Chenais, E., 2021. African swine fever epidemiology, surveillance and control. In: Iacolina, L., Penrith, M.-L., Bellini, S., Chenais, E., Jori, F., Montoya, M., Ståhl, K., Gavier-Widén, D. (Eds.), Understanding and combatting African Swine Fever: A European perspective. Wageningen Academic Publisher, Wageningen.

White, M.D., Marsh, E.E., Marsh, E.E., White, M.D., 2006. Content analysis: a flexible methodology. Libr. Trends 55, 22–45.

Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L.D.A., François, R., Grolemund, G., Hayes, A., Henry, L., Hester, J., 2019. Welcome to the Tidyverse. J. Open Source Softw. 4, 1686.