

**ASSESSING THE IMPLEMENTATION AND ECONOMIC IMPACT OF
AFRICAN SWINE FEVER CONTROL ALONG THE PIG VALUE
CHAIN**

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DECLARATION

I, **Aliro Tonny**, hereby declare that this thesis is my original work and has never been presented to any institution of higher learning for the award of a degree.

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APPROVAL

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DEDICATION

This dissertation is dedicated to my parents Okabo Gideon Jack (RIP) and Mongo Elwor Alice Okabo; my lovely wife, Mrs. Beatrice Aliro and our children – golden boy “Okabo Gideon Jack”, Apio Maria, Mongo Prosy, Auma Joy Patience, Akwech Timothy Maxwell and Aliro Johnasan Emmanuel; my brothers and sisters – Achol William, Auma Norah (RIP), Okabo Sam, Akello Florence, Ayo Thomas, Odongo Henry, Nyankori Grace, and Ayugi Anna.

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LIST OF ABBREVIATIONS/ACRONYMS

ASF	African swine fever
ASFV	African swine fever virus
DVO	District Veterinary Officer
EDTA	Ethylenediamine Tetra-acetic Acid
FAO	Food and Agricultural Organization of the United Nations
FAOSTAT	Food and Agriculture Organization Statistic
FGD	Focus Group Discussions
GMB	Group Model Building
GUREC	Gulu University Research Ethic Committee
HBM	Health Belief Model
IMF	Investigated Modern Farm
IK	Indigenous Knowledge
KII	Key Informant Interview
MAAIF	Ministry of Agriculture Animal Industry and Fisheries.
NAADS	National Agricultural Advisory Service
NDP-IV	Fourth National Development Plan
OIE	World Organization for Animal Health
PVC	Pig Value Chain
RO	Research Objective
RT-PCR	Real-Time Polymerase Chain Reaction

GENERAL ABSTRACT

Pig production recommended as key for poverty alleviation strategies in Uganda's 2040 Vision, contributes to livelihood income and employment for many people. The potential of pig value chain to support the livelihood of people are impacted economically by factors related with African swine fever (ASF). The endemic ASF has no effective vaccine and medicine, prevention and control rely on biosecurity measures, and restrictions of trade and pig movements. The overall goal of this study was to advance knowledge of perceived existing ASF biosecurity measures and associated implementation cost in the pig value chain. Four studies were conducted in six districts across northern, and central Uganda. The studies used focus group discussions, disease outbreak investigations, and participatory group model building of system dynamic (SD). Data analysis included semi-qualitative and quantitative methods. This study classified the perceived biosecurity implementation in smallholder into enablers – positive perception and knowledge; and hindrances – investment and feeding costs. Anthropogenic activities introduced ASFV contaminated commercial feeds into and facilitated spread within and across pig houses of a large-scale modern farm. During quarantine imposition, value chain actors shifted trade activities from formal to informal markets, and the perceived economic loss was higher among farmers. Farmers forgone pig sales worth \$160,000, which is \$14,000 lower than what traders would sell as pork during trade ban. In SD simulation scenarios when consumer demand remains unchanged, adult pig numbers rose as sales were restricted, hence pig and pork inventory reduce, causing an increase in prices as less is available on the market. On the other hand, when consumer demand falls, pig inventories rise and this causes a decline in the pig price. Combining a trade ban with enhanced biosecurity cost when consumer demand falls resulted in a further increase in adult pigs and pig inventories due to reduced pig death rates. As trade bans induce an increased herd size on farm, this leads to a fall in farmer and trader profit margins. In conclusion, the existing biosecurity measures have failed to prevent and control ASF as hindrances outweigh enablers of biosecurity implementations. Contaminated commercial feeds was a potential source for ASFV introduction into large scale farmer. Reducing the pig mortality rates through enhanced biosecurity can improve outcomes from ASF outbreaks during trade ban, but there is a trade-off with greater incurred costs.

Keywords: ASF quarantine, Biosecurity, Economic impact, Pigs, Pig value chain

CHAPTER ONE: GENERAL INTRODUCTION AND RESEARCH OBJECTIVES

1.1 Background of the study

Pig production is practiced widely across Africa due to its immense contribution to the livelihood for many of rural population (Adesehinwa et al., 2024). As a result, pig industry has the potential to attain the United Nations Sustainable Development Goals on Zero Hunger and Poverty Eradication, especially, by providing high quality animal protein rich in micronutrients (vitamin B12, calcium, and iron) to bridge the deficit in the protein requirement for the rapidly growing human population in African countries including Uganda (Delgado, 2003; Adesehinwa et al., 2024; Zduńczyk et al., 2024). Uganda is a low-income country with a high potential for developing its livestock industry (Wabukala, 2018), where pig production has been recommended as key for poverty mitigation strategies in the Uganda 2040 Vision and the fourth National Development Plan (NDPIV) 2025/26–2029/30 (National Planning Authority, 2024). Pig production in Uganda is dominated by smallholders, who constitute more than 90% (World Bank, 2017). Pig farming has become very popular throughout the country because of the contribution to food security, livelihood income and employment for many people (Ouma, 2014; Ouma et al., 2017; Sentumbwe, 2017). Smallholder farmers produce pigs mainly for sale, only on rare occasions are pigs slaughtered for family consumption (Nyapendi et al., 2004). The smallholder pig value chain, including actors such as farmers, traders, butchers, middlemen, and pork-joint operators, represents a source of livelihood for more than 2.2 million households in Uganda. The figures for pig population increased from 3.2 million in 2008 to 7.1 million in 2021 according to livestock census data (UBOS, 2024).

Three pig production systems, that is free-range, semi-intensive and intensive, with herd sizes ranging from 2 to 20 pigs generally characterize Uganda's pig industry. In general, herd sizes are larger and the proportion of pigs kept in intensive or semi-intensive systems is higher in peri-urban and urban areas compared to rural areas (Muhanguzi et al., 2012; Ouma et al., 2013). Feeding strategies among smallholders farmers change depending on feed availability across the seasons (Ouma, 2021), and the financial capability of farmers to either purchase raw materials to formulate own pig feeds or access commercially formulated pig feeds (Okello et al., 2021). Rural farmers feed pigs mostly on crop residues or forages, whereas those in peri-

urban or urban areas provide raw peelings such as bananas and cassava, or swill from restaurants or owners' kitchen, and formulated feeds (Beyihayo et al.2015).

Provision of veterinary care and advice to smallholder farmers are of limited, farmers often rely on paraprofessionals, also called Paravets, as their main source of veterinary service (Dione et al., 2014a; Gertzell, 2020). Further, traditional and ethnoveterinary medicine is sometimes also used (Dharani et al., 2015). Other services such as artificial insemination are uncommon among smallholder pig famers. More than half of smallholder pig farmers in Uganda do not own breeding boars (Bamundaga et al., 2018). Hiring boars for breeding is thus common (Chenais et al., 2023a). Breeding boars are usually hired from neighboring farmers based on a common understanding regarding payment for the breeding service. Payment is done through cash or a piglet in-kind (Dione et al., 2014b).

Market systems in the pig value chain are largely informal; pigs are usually sold by farmers directly to butchers and traders or indirectly through middlemen. Purchased pigs are transported to rural trading centres or urban areas for slaughter. In the smallholder value chain, pig slaughter is mostly done at informal slaughter slabs without veterinary inspection or the possibility of maintaining even basic slaughter hygiene. Traders pay a fee per pig to use the designated slaughter facilities (Mtimet, Baker, & Ouma, 2018). The processed pig products (carcasses or pork) are distributed to pork retail outlets such as butcheries, pork-joints and restaurants. Pork consumption is highest during weekends, public holidays, festive periods like Christmas and Easter, and when there is scarcity of other food items. Uganda has the highest pork consumption in East Africa with an estimated annual per capita pork consumption of 3.4 kg (FAO, 2021).

The potential of the smallholder pig value chain to support the livelihood of all the people that are involved in the value chain are limited by several factors including disease management and feeding issues that affect pig growth and productivity. Of particular interest is the African swine fever (ASF) disease, which causes severe economic impact losses to majority of farmers in Uganda (Dione et al., 2014b; Kungu et al., 2019).

1.2 African swine fever disease (ASF)

African swine fever is caused by African swine fever virus (ASFV), a large DNA virus of the genus *Asfivirus* and family *Asfarviridae* (Dixon et al., 2005). It is contagious disease which affects domestic and Euroasian wild boar of all breeds and ages presenting with hemorrhagic fever (Penrith et al., 2013). The clinical presentation is typically acute, resulting in high case fatality rate, but can also present as subacute, or from apparently asymptomatic to chronic depending on virus strain and immune status of the animal (Gabriel et al., 2011; Sánchez-Vizcaíno et al., 2015). Highly virulent strains cause per-acute to acute ASF with signs such as hemorrhages in the skin around ears and belly, high fever (over 40°C), and death with mortality rate of nearly 100% (Kleiboeker, 2002; Penrith & Vosloo, 2009) following outbreak in an area.

Since its first outbreak was described in Kenya in 1920s (Montgomery, 1921), ASF has spread to many countries globally, including Uganda. In Uganda, previous study reported ASF outbreaks occurrence through the entire period between 2012 and 2021, with the highest number in central region (181), followed by eastern region (100), northern region (60), western region (23), and only 12 outbreaks each in Southwestern and West Nile regions (Atuhaire et al., 2013). Generally, ASF has remained endemic in Uganda (Mulumba-Mfumu et al., 2019; Okwasiimire et al., 2023) despite existing control strategies.

1.2.1 African swine fever control strategies

Recommended control strategies for ASF include strict biosecurity measures developed as standards set to prevent ASF outbreak in the farm and reduce ASF spread within and across farms including other nodes along the pig value chain. At farm level they are confinement of pigs in pigsty, cleaning and disinfection (of premises, tools, equipment, and protective gears), quarantine of new pigs bought from the market or other farmers, quarantine of unsold pigs from the market away from host pigs at home, isolation of sick pigs from healthy ones, and restriction of people accessing pigs (Ohouko et al., 2020; Miller, Miknis, & Flory, 2020; Mutua & Dione, 2021; Chenais et al., 2022). Furthermore, the boiling of swill meant for feeding pigs, proper disposal of manure as well as dead pigs through burning to ash or burying 6 feet deep (FAO, 2010a; Dione et al., 2020a; Chilundo et al., 2020). Beyond farm level, the recommended biosecurity measures at other nodes are to avoid trade in sick pigs and infective pig products, inspection of live pigs and pig products for quality assurances before sale or moving with a health certificate to accompany pigs in transit, movement restrictions of pigs and its products,

and safe disposal of pig tissues such as intestine, blood, and hair left at slaughter slabs and pigs that died in transit or holding facility. It is expected that applying these measures will result in an overall increase in pig productivity and improve livelihoods of stakeholders. Guidelines for setting up clean value chains that reduce the risk of ASF to an acceptable level are available for smallholder pig production in Asia and can be more widely applied in other countries (Kim et al., 2022). The implementation of this guideline needs stakeholders' cooperation.

Uganda government as a stakeholder has a role to play in prevention and control of animal diseases through livestock sector in the Ministry of Agriculture Animal Industry and Fisheries (MAAIF). MAAIF is responsible for animal disease surveillance, early detection, reporting, vaccination and quarantine imposition. Since the imposition follows request from District veterinary officers (DVOs) regarding confirmed ASF outbreaks in their districts, DVOs are mandated to enforce the set regulations to control the spread of ASF. In countries where quarantine is imposed during disease outbreak, the goal is to restrict movement of animals and animal products, enforced farm biosecurity, and slaughter of affected or exposed animals (Sánchez-Cordón et al., 2010).

1.3 Problem statement

According to Mutua & Dione (2021) knowledge of the key principles of biosecurity is fundamental if farmers and other value chain actors want to substantially change their perception of disease risks, and consequently increase their level of awareness of the importance of biosecurity measures. The perceptions of disease bring into focus the concerns individuals (such as farmers) have about how they and animals live their lives, their relations to community, environment, and explanation of suffering due to sickness (Anderson, 1999). Farmers constantly interact with pigs through routine husbandry and hygiene practices, traders are aware of existing biosecurity measures such as disease reporting, but do not perceive themselves as key actors in controlling ASF (Dione et al., 2016a; Atherstone, 2019). Considering lack of compensation by the government and prioritizing household income earnings, farmers perceived selling of sick animals as the best option to realize some funds from their pigs rather than to leave them to die of ASF during outbreak (Nantima et al., 2016; Dixon et al., 2020). Furthermore, the perception that ASF kills all pigs in the infected pig herds motivates farmers to slaughter sick pigs before they die (Roesel et al., 2019b). Such pig products remain a potential source of infection for healthy pigs along the value chain. Different risk factors for ASF are present in different types of farms (Muhangi et al., 2015; Dione et al.,

2016a; Dione et al., 2017a; Chenais et al., 2017a. Dione et al., 2018; Ekakoro et al., 2023). Confinement is a pre-requisite for most biosecurity measures, and in Uganda most pigs in smallholder farming are in free-range management systems. In total confinement, ASF risk factors are all means of direct and indirect contact between infected and naive pigs or products, and the different ways this can occur if pigs are confined or not. Confined pigs expose to stray pigs and feeds from unknown sources make them more vulnerable to ASF infection. Outside the farm, continuous trade in live pig and pig products during ASF outbreaks have been documented as risk factors for spread of ASF in Uganda (Dione et al., 2016a) and other parts of Africa (Penrith et al., 2019). Uganda like any other African countries, policymaking processes in the livestock sector is ineffective (Scoones & Wolmer, 2006). There is no an explicit national policy or regulatory framework for ASF control in Uganda, despite availability of policies and legal instruments which could potentially enhance ASF prevention and control in the country (Dione, Nantima, et al., 2017). Chief veterinary authority in Uganda, imposes quarantine and movement restrictions following confirmed ASF outbreaks, but the implementation is always very poor (FAO, 2021a). Farmers in Uganda don't respect quarantine measures since the government does not have disease control policy of compensation schemes to eliminate the infected and in-contact animals (Muwonge et al., 2012).

African swine fever outbreaks reported in Uganda from smallholder pig farms in Uganda have been widely blamed on inadequate implementation of biosecurity measures (Nantima et al., 2015a; Nantima et al., 2016; Mutua & Dione, 2021). The biosecurity implementation challenges on smallholder farms are different from those found in large commercial farms. Key hindrances to biosecurity implementation in the smallholder value chain include poverty resulting in low investment in biosecurity; high financial cost for establishing and implementing effective biosecurity; sociocultural and traditional barriers debarring people from burying dead animal (Dione et al., 2020a; Pao et al., 2022; Chenais et al., 2023a) and behavioural and psychosocial factors influencing peoples adoption and adherence to the recommended biosecurity measures (Mankad, 2016). In large scale farms with large number of pigs and movements, stricter biosecurity measures are needed than in smaller farms. Confining pigs may be necessary for ASF control (FAO, 2010a), but associated investment cost remains a big challenge in the resource constrained settings. Cost of investing in biosecurity is perceived as a loss of household income (Dione et al., 2020a).

1.4 Knowledge gaps in ASF disease control

1.4.1 African swine fever biosecurity measures

Knowledge on biosecurity is one of the key drivers that influence actors behaviour towards effective implementation of existing measures (Young et al., 2015; Cui et al., 2016). Although other researches highlighted farmers' knowledge and attitudes as factors determining biosecurity implementation (Alawneh et al., 2014; Young et al., 2015; Ritter et al., 2017; Chenais et al., 2017b), farmers' knowledge on biosecurity measure for ASF control is never perfect. Recent studies have shown that lack of knowledge is no longer binding constraint to adoption of the feasible biosecurity interventions (Randrianantoandro et al., 2018; Dione et al., 2020a). Knowledge varies across communities (Thomas, 2008) because of cultural variations (Somnasang & Moreno-Black, 2000), and geographical diversity. All over, farmers can understand how problems are link to their routine activities, and how their livelihoods can be affected if such problems are not addressed, but knowledge of how farmers implement the existing biosurity measures during outbreak is not known.

According to FAO (2013), two major challenges contribute to failures in achieving control of animal diseases: lack of Government's understanding of disease dynamic and meeting the needs of livestock value chain actors which are specific to their local setting, and why farmers are unable to adapt to their needs remain unknown. Previous research in Uganda called for more locally adapted biosecurity measures to reduce the spread of ASF and the negative impacts in poor smallholder contexts (Chenais et al., 2019a; Thompson, 2021). However, recent research further provides evidence that participatory involvement of value chain actor in the adoption of biosecurity measures to the local context, while paying attention to their own needs, can increase implementation as well as strengthen cooperation and community ownership of the disease and its control (Chenais et al., 2023b). Therefore, knowing actors' needs may be paramount for effective prevention and control of ASF

Previous studies in Uganda have also investigated failed biosecurity, attitudes towards biosecurity, and general knowledge regarding participatory research (Nantima et al., 2016; Chenais et al., 2017b; Chenais et al., 2017c). These three studies all highlighted that local acceptance and adoption of biosecurity are key for successful implementation. Another study showed that smallholder farmers have positive attitudes towards the effectiveness of biosecurity protocols, and yet they invest very little into it (Kabuuka et al., 2014; Chenais et al., 2017b; Chenais et al., 2019a). Combining their perception with measures with knowledge,

and attitude towards existing biosecurity measures can improve the implementation of ASF prevention and control along PVC.

In several studies on ASF control, epidemiology, ASFV, value chains and risk factors over the past years, farmers have been the most investigated target group (Nantima et al., 2015a; Nantima et al., 2016; Dione et al., 2020a). Involvement of all the actors in the implementation of biosecurity measures is very important since every actor has the responsibility to play in the t

1.4.2 Economics of ASF control measures

Economic impact is the effect an event, especially something new, has on economic output, a situation or a person. In this study, the events are ASF and the related control measures, and how these events affect the business of pig value chain actors. Identifying the economic burden of a disease is useful to understand the maximum amount of resources that could be saved or gained if that disease were to be partially or fully eradicated (Rice, 1967).

In Uganda, most of the economic studies done so far have been on direct economic impact of ASF on farmers due to death of pigs during confirmed outbreaks (Muhanguzi et al., 2012; Atuhaire et al., 2013a; Dione et al., 2014a; Ekakoro et al., 2023). In the context of pig mortality, studies done in Uganda indicated that the impact of ASF is felt more in areas with high pig population density and the impact is aggravated with increasing herd size (Dione et al., 2014a; Chenais et al., 2017c). Since pig farming is a livelihood source farmer could have incurred economic losses in attempting to reduce rate of pig deaths during the outbreak. Among the reported negative effect are farmers' unwillingness to restock pigs, reduced positive attitudes towards pig rearing, and lack of will to invest in biosecurity meant to prevent and control ASF in the farm (Chenais et al., 2019a; Arvidsson et al., 2023).

Previous qualitative research methods, not directly on ASF control, have been used for assessing social impact of ASF in Uganda. These include impact assessments of ASF outbreaks which reported negative impacts linked to pig mortality (Chenais et al., 2017b; Chenais et al., 2017c). These studies described economic impacts which would have been avoided if pigs were not dead, and social impacts such as reduced frequency of pork consumption, failure to pay school fees and medical bills. Other socio-economic studies reported the unwillingness of farmers to restock new pigs and invest in biosecurity, due to fears of future disease reoccurrences (Chenais et al., 2019a; Arvidsson et al., 2023). The contribution of high cost of

pig feed ingredients and unorganized pig markets to failure of ASF control, documented in Uganda has been documented (Ouma et al., 2015) was limited to a smaller area. Previous research noted that farmers' payment for treatment of pigs with suspected ASF costs and without curing the animal (Ilukor et al., 2015a; Arvidsson et al., 2023). Studies done in Uganda and elsewhere, demonstrated that investment on farm biosecurity measures reduced both the ASF incidences and farmers profit-margin, but other value chain benefitted as their profit-margin increased (Fasina et al., 2012a; Ouma et al., 2018). These studies considered cost biosecurity implementation at farm level to control ASF at farm, not at nodes downstream of PVC. Profitability is a key principal driver for farmers' involvement in pig rearing, in that way, understanding how this driver can be used to maintain biosecurity principles in the farm is important in ASF control (Fasina et al., 2012a). A study reported that, it is a big challenge to maintain low ASF incidence in domestic cycle without threatening the survival of poor farmers, aimed at having a sustainable and profitable pig enterprise (Penrith et al., 2019).

In order to implement animal disease control for profitable marketing of animal and animal products, Costard et al. (2012) advocated for market-based or certification approaches in the control of ASF. Similarly, commodity-based approach used sanitary and phytosanitary (SPS) certification costs in the case of beef exportation from Foot and Mouth Disease endemic countries (Rich et al., 2009). A system dynamics (SD) approach with group model building demonstrated that ASF risk mitigation along value chains can be done through implementation of biosecurity measures (Ouma, 2018). The need to combine biosecurity implementation with development of business hubs has been recommended for designing a safer, effective and profitable ASF control strategy in a system suitable for pig value chain actors (Ouma et al., 2018; Penrith et al., 2023). However, more information about the existing resources and economic drivers are needed for designing risk-based biosecurity measures that are feasible, affordable, socio-culturally acceptable and cost-effective in the PVC.

1.5 Conceptual framework

In line with ASF control challenges described in section 1.3, a conceptual framework for this study is presented in Figure 1.1. The framework shows how the perceived existing biosecurity measures influence the outcome of its implementation. Success of implementation influences level of economic losses associated with ASF control. The conceptual framework presents the inter-relationship between these variables with each inter-relationship reflecting a specific research objective that was investigated in this study.

The frequent occurrence of ASF outbreaks in Uganda and the challenges associated with effective implementation of biosecurity measures along the value chain prompted this study to explore stakeholders' perception of existing biosecurity measures and the economic impact of control measures.

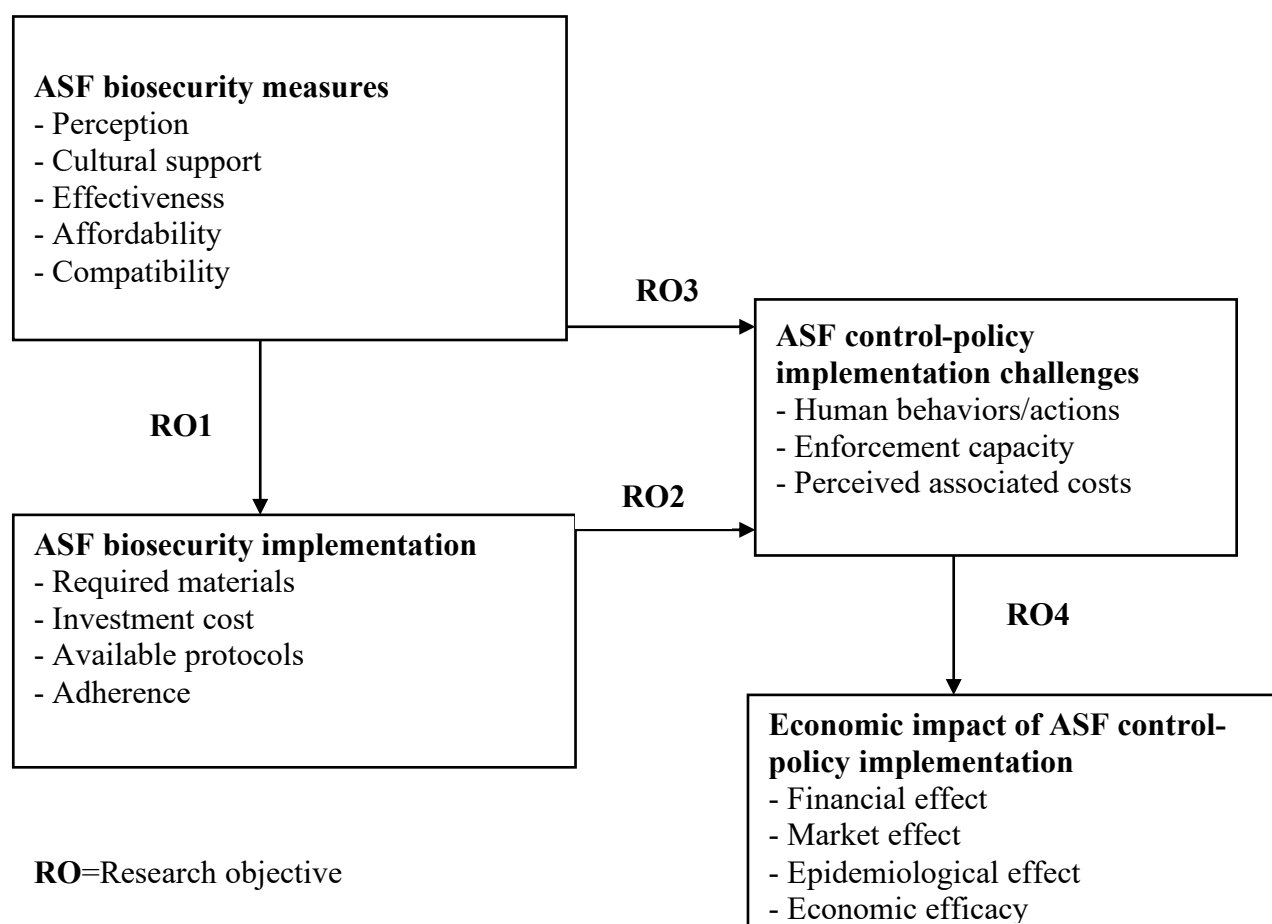


Figure 0.1: Conceptual framework and research objectives

1.6 Research objectives and questions

1.6.1 General objective

The knowledge gaps identified in section 1.4 motivated this study. The overall objective was to advance knowledge of stakeholders' perception of current ASF biosecurity measures, their implementation and the associated economic implications for improvement of ASF control in the pig value chain. The four specific objectives of the study are:

1.6.2 Specific objectives

The specific objectives of these study were:

1. To assess stakeholders' perception of ASF biosecurity measures used in the PVC in Northern Uganda.
2. To identify risk factors associated with introduction and spread of ASF in large-scale farms to extrapolate biosecurity implementation to other farms.
3. To assess actions taken by different stakeholders and the perceived economic impact during quarantine.
4. To analyse economic impact quarantine imposition on smallholder value chain

To address each of the specific research objectives, several research questions were answered. Table 1.1 provides an overview of the research questions linked to each of the objectives.

Table 0.1: *Summary of research objectives and questions*

Research Objectives (RO)	Research Questions (RQ)
RO1: To assess the stakeholders' perception of current ASF biosecurity methods used in smallholder pig value chain in Northern Uganda.	RQ1: 1. What are the perceived existing biosecurity measures under local setting? 2. Which drivers influence success of biosecurity implementation under local setting? 3. What are the factors hindering the implementation of biosecurity measures under local setting? 4. Do you think what you have are enough to protect pigs? 5. Is the current status quo trying to protected pigs? 6. Were some pigs surviving despite past outbreak waves?
RO2: To identify the risk factors associated with introduction and spread of ASF in a large-scale commercial farm.	RQ2: 1. What is the inflow of pigs and people into the farm? 2. How are farm inputs sourced and delivered to the farm? 3. Are workers complying with the available biosecurity protocols? 4. What is the flow movement of pigs, workers and fomites within the farm?
RO3: To assess the actions taken by different stakeholders and the perceived economic impact during quarantine.	RQ3: 1. What actions were taken by actors during quarantine imposition? 2. How were different actors affected? 3. Which actors were most affected and why? 4. What are the perceived losses? 5. Did you have any benefit from trade ban, pigs protected
RO4: To analyse the economic impact of quarantine imposition on smallholder value chain	RQ4: 1. What was the financial losses incurred by traders and farmers? 2. How did market demand affect prices and inventories of both live pigs and pig products? 3. What was the epidemiological and financial benefits of the intervention? 4. How were traders and farmers' profit margins affect?

1.7 Significance of the study

Space requirement for keeping pig is small compare to other domestic animals such as cattle, sheep, and sheep. As a result, almost everyone is able to keep pigs as a sources of livelihood income. Pigs can feed on kitchen leftovers and inexpensive readily available feeds such as forage and crop residues to improve household nutrition and income. However, outbreaks of ASF has persisted despite attempts made by farmers using the available limited resources to prevent outbreak and control wide spread in the community. The development of control strategies which are feasible, acceptable, affordable and economical beneficial to value chain actors and in-turn will support rapid growth in the piggery sector. Increased pig production, can improve both household nutrition and food security, enhance employment opportunities, increase household income in terms of revenue gains among actors along pig value chain, and also contribute to transforming the economy form a peasant to a prosperous one. All these will fit within the fourth National Development Plan (NPPIV) especially pillars number one and two, Uganda's Vision 2040, and the Sustainable Development goals number one, two and eight.

CHAPTER TWO: LITERATURE REVIEW

2.1. Ugandan Pig sector

2.1.1 Pig production

Pig production in Uganda is widespread, and the number of households keeping pigs increased from approximately 1.1 million (17.8%) in 2008 to 2.2 million (32.8%) in 2021 in which at least one pig was owned (UBOS, 2024). According to the National Livestock Census of 2021 (UBOS, 2024) the regional distribution of pigs in Uganda was greatest in the Western region (32.3%), followed by the Central (32.2%), Eastern (19.7%), Northern (14.7%) and Karamoja subregions (1.1%). Over the years, government and NGO programmes have popularized piggery as one of the ways to eradicate poverty in the country (Tatwangire, 2014). The government used its National Agricultural Advisory Services (NAADS) and Operation Wealth Creation (OWC) programmes alongside several NGOs, such as the Child Fund, Feed the Hungry and World Vision to supply breeding pigs to farmers (Tatwangire, 2014). These pig distribution to farmers, all together boosting growth in the pig industry. Pig production in Uganda is predominantly smallholder, with 80% of farmers owning between 1–5 pigs (Ouma et al., 2015), composed of 1 to 2 sows and 3-5 fattening pigs per smallholder (Ikwap et al., 2014; Ndyomugenyi & Kyasimire, 2015) Indigenous breeds are predominantly reared among small holders (Ikwap et al., 2014; Ndyomugenyi & Kyasimire, 2015), due to their adaptability to the prevailing environment conditions and to the low-input systems.

Rural farmers feed pigs mostly on crop residues or forages, whereas those in peri-urban or urban provide raw peelings such as bananas and cassava, and swill from restaurants or owners kitchen. Use of formulated feeds is currently picking up in smallholder pig farming (Okello et al., 2021), although is common among financially capable farmers who can either purchase raw materials (maize bran, rice bran, and fish meal) to formulate own pig feeds or can access commercially formulated pig feeds especially those who lacks feed formulation skills. Smallholder farmers rely on paraprofessionals as their main service providers (Dione et al., 2014; Gertzell, 2020). With low qualification level of paraprofessionals, the quality of health services offer to smallholders farmers are inappropriate for sick animals to recovery from diseases (Dione et al., 2014);(Ilukor, 2016). Artificial insemination service is uncommon, farmers rely on hired boars for breeding (Chenais et al., 2023a), and payment is done through cash or in-kind using a piglet (Dione et al., 2014b).

2.1.2 Importance of pig production

Pig rearing has advantage over ruminants because of lower investment costs. Pigs do not compete for pasture land, can be used for transforming kitchen waste into food and have a short reproduction cycle, allowing for quick financial turnover (Phiri et al., 2003). Because pig is among small livestock species, it can easily be raised by resource poor people importantly as an immediate source of household income and financial security (Ampaire and Rothschild, 2010; Ouma et al., 2014). Pigs have a high feed conversion efficiency, high dressing percentage (65-80%), large litter size, can utilize wide variety of feed stuffs, require small investment on housing and equipment, are highly prolific and provide quick returns to farmers (Ndyomugenyi & Kyasimire, 2015). Pigs can farrow twice annually and have the potential to produce large litter sizes. Farmers can sell offspring at any stage of growth as piglets, growers or adult depending on the magnitude of financial needs at that moment. Since pig is a small livestock, farmers can also slaughter a pig and sell all the carcass in the village. In Uganda, pork retail businesses concentrated in village trading centres and along road-side are transacted through informal pork butcheries and pork eating places so-called “pork joints” (ILRI, 2011; Ouma et al., 2013; Dione et al., 2014). Pork is a delicacy and on high demand in Uganda. The per capita consumption of pork in Uganda currently ranks highest in East Africa at 3.4 kg per year (FAO, 2018). In addition to providing household income, pig provides one of the cheapest form of high quality animal protein, with pork accounts for over 36% of meat eaten globally (Delgado, 2003; Chenais et al., 2017c; Dione et al., 2017a; Carter et al., 2018).

2.1.3 Pig marketing dynamics

Market systems are largely informal, pigs from village systems are usually sold directly to butchers and traders or through middlemen based on oral agreement. Purchased pigs are from smallholder farmers are transported to trading centres or urban areas for slaughter. According to Ouma et al., (2017) pigs are usually slaughtered in unregulated premises adjacent to pork retail outlets such as pork-joints or butcheries. Most smallholder traders/butchers collectively slaughter such slaughter premises, most time owned or rented by one of the members. However, other slaughters are done in designated such as under trees, and in slaughter slab or abattoirs. In the smallholder pig production value chains pig slaughter is mostly done at village slaughter slabs without veterinary inspection or the possibility of maintaining even basic slaughter hygiene (Penrith et al., 2021). The carcasses or pork from slaughter places are distributed to the different outlets which include butcheries, pork-joints and food restaurants.

Traders or butchers sell pork mainly under a tree along road sides, in a trading centre, a super market, a daily market, a pork butcher or a pork joint. Pig products are largely consumed in cities, and towns due high demand from large human population in those areas. Pork consumption is highest during festivals such as public and religious periods, and when of low food availability, hence increasing its potential to contribute to food and nutritional security (Tatwangire 2014). In the subsistence farming systems in ASF endemic countries in Africa trade and slaughter have been identified as important for disease transmission (Fasina et al., 2012)

2.2. Transmission of African Swine Fever

2.2.2 ASF Epidemiology

African swine fever virus transmission occurs through direct or indirect contact in four different, but overlapping epidemiological cycles (Costard et al., 2009a; Chenais et al., 2018) involving warthogs (*Phacochoerus africanus*), soft ticks (*Ornithodoros* spp), domestic pigs (*Sus domesticus*) and Eurasian wild boar (*Sus scrofa*). The epidemiology varies depending on the different systems and hosts, which can be described as different cycles. The cycles include sylvatic cycle, tick-pig cycle, domestic pig cycle and wild boar–environment cycle are shown in Figure 2.1. Individual cycles are described below the figure.



Figure 2.1: Portraying four epidemiological cycles. Source, (Chenais et al., 2018)

2.2.2.1 Sylvatic cycle (number 1)

In the sylvatic cycle, ASFV circulates between the soft ticks and wild pigs, especially in warthogs which is well described in eastern and southern Africa (Thomson, 1985; Plowright

et al., 1994). The vector, *Ornithodoros* species of soft tick are responsible for maintenance of the ASFV in wild pig population. A young warthog bitten by infected *Ornithodoros* ticks while in the barrow, becomes infected, and develops viraemia lasting for two to two to three weeks. Viremic young warthog can infect *Ornithodoros* ticks feeding on them (Thomson et al., 1980; Thomson, 1985). Direct transmission of ASFV from sick warthog to healthy warthog is not possible. Sylvatic cycle mode of transmission has been reported in Uganda.

The role of bush pigs (*Potamochoerus larvatus*) remains largely unexplained although their role as free-living hosts of ASFV has been demonstrated both experimentally and under natural condition (Oura et al., 1998; Luther et al., 2007). Although bush pigs develop sufficient viraemia to infect *Ornithodoros* spp and domestic pigs, they seem to require high levels of virus to become infected than domestic pigs (Anderson et al., 1998). In Africa, the giant forest hog (*Hylochoerus meinertzhageni*) has also been reported although its role is still considered negligible (Penrith et al., 2004).

2.2.2.2 Tick – pigs cycle (number 2)

In tick-pig cycle, *Ornithodoros* ticks that fed on viremic wild-pig can maintain ASFV infection for months to years. The ticks serving as a reservoir of virus can persist in the local environment such as infestation of pig pens described in Africa and the Iberian Peninsula (Wilkinson, 1984) (Haresnape et al., 1988). Previous studies in Spain linking outbreaks in domestic pigs with presence of ASFV in *Ornithodoros erraticus* tick found in the area (Pérez-Sánchez et al., 1994) suggested that transmission of ASFV from wild pigs to domestic pigs by ticks was a probable source of outbreaks. In Portugal, ASF is thought to have re-emerged in 1999 on a previously infected farm due to the continued presence of *Ornithodoros erraticus* ticks (Sánchez-Vizcaíno, et al., 2009; Boinas et al., 2011). Although the indirect transmission of ASFV by ticks to domestic pigs has not been described in Uganda, infected ticks collected from warthog barrows has been demonstrate (Plowright et al., 1994). However, the indirect transmission involving wild and domestic pigs sharing garden and water sources could aid the transmission of ASF disease as reported in Uganda (Kukielka et al., 2016).

2.2.2.3 Domestic – pig cycle (number 3)

In this cycle amongst domestic pig population, ASFV transmissions occur through direct contact between domestic pigs or indirectly from pig products to domestic pigs and with

contaminated fomite (Plowright et al., 1994; Sánchez-Vizcaíno et al., 2012). ASFV is shed in the secretion and excretion of domestic pigs during viremic stage of infection. ASFV may remain viable in blood and tissues for long periods, and transmission through direct contact can thus occur for several weeks (Wilkinson and Pensaert, 1989). In sub-Saharan Africa countries including Uganda, most ASF outbreaks in domestic pigs are associated with domestic cycle (Penrith et al. , 2019; Penrith et al., 2023).

2.2.2.4 Wild boar–environment cycle (number 4)

This cycle involves direct transmission between wild boars (*Sus scrofa*) or indirect transmission by wild boars coming in contact with the ASFV contaminated habitats (Chenais et al., 2018). The habitat contaminated with ASFV infected wild boar carcasses can be a source of new infection depending on landscape, time, season and carcass decomposition (Probst et al., 2017). Unlike with African wild suids, wild boars transmit ASFV efficiently, they become clinically sick and there is high case fatality rates (Blome et al., 2013). Environmental persistence of the virus is favoured by cold and moist climate.

2.3 ASFV circulation in Ugandan domestic pig population

In spite of the presence of the sylvatic cycle, most ASF outbreaks in Uganda are associated with the domestic pig cycle, just as in most other parts of the world (Penrith et al., 2019a; Penrith et al., 2023). In domestic-pig cycle, the transmissions can be direct contact between infected and naïve pigs or indirect contact through ingestion of infected pork or other contaminated materials (Nantima et al., 2015a; Dione et al., 2018). The cycle is driven by actions of stakeholders performed along smallholder pig value chain (Ouma et al., 2018; Penrith et al., 2019). Pig movement network and trade activities along smallholder value chain with poor biosecurity play key roles in the transmission of ASFV in domestic pig cycle (Lichoti et al., 2017; Ouma et al., 2018; Matsumoto et al., 2021; Mutua & Dione, 2021). Furthermore, Transmission is also associated with traditional and cultural beliefs such as unacceptable burial of carcasses, feeding pigs on swill, free rang practice and poor implementation of other known biosecurity measures (Muwonge et al., 2012; Nantima et al., 2015; Chenais et al., 2017). The ASFV genotypes circulating in Ugandan domestic pig population is mainly genotype IX based on the p72 protein (Bastos et al., 2003; Gallardo et al., 2011).

2.4 Properties of ASFV

To get the insight of higher molecular level, with the purpose of understanding the source and spread of outbreaks, knowledge of ASFV properties is paramount. ASFV can maintain their stability and longevity in most natural environments when protected by organic material. ASFV has double-stranded DNA genome which encodes different enzymes and proteins that is responsible is repair and protection DNA. These properties help in maintaining the genome integrity and stability (Dixon et al., 2004); (Correia et al, 2013); (Sereda et al., 2023). The virus can remain infectious under various conditions such as PH level of 4-13 and for 75 week in blood stored at 4⁰C (Plowright & Parker, 1967); 18 months in serum with preservation (Montgomery, 1921) including 12 month when stored at room in serum; and upto one week in faeces and urine at 37⁰C (Davies et al., 2017). The virus is stable for 120 days in frozen fresh meat (Mebus et al., 1997); and in traditionally dried and cured pork it can remain viable upto up to 399 days (Mckercher et al, 1987); (Mebus et al., 1997). Montgomery, (1921) demonstrated that ASFV is resistant at extremely high temperature; can remain viable after 1 hr of incubation at 56°C and one week at 37°C. The stability and survival time of the virus increases in the presence of organic matter, such as blood, serum, and uncooked meat or meat products (Dixon et al., 2019); (Prodelalova et al., 2022). As a result, African swine fever virus can survive and spread in different seasons, climates, and pH conditions (Andrés et al., 2020).

2.5 ASFV diagnostics

Identification of ASFV presence in sick animals is usually performed sequentially: virus isolation, detection of viral antigens, virus genome or antibodies against viral proteins (OIE, 2012). Detection of virus antigens can be done by fluorescent antibody tests and by enzyme-linked immunosorbent assay (ELISA), whereas detection of viral genomes can be done by both real-time and conventional polymerase chain reaction (PCR) assays (OIE, 2012). Detection of viral genome using PCR is the most sensitive technique of these; in addition, it is rapid and can be done on putrefied samples. With PCR, the ASFV genome can be detected from tissues, serum and blood at a very early stage in the infection. It is therefore often the most suitable technique (OIE, 2012). Antibodies can be detected by indirect fluorescent antibody tests or ELISA. Detection of antibodies have a limited diagnostic value as their presence will not differentiate between ongoing or older infections. Furthermore, in the hyper-acute and acute forms of ASF, the pigs often die before antibodies have developed. ELISA-procedures are often fast, cheap and easily automated. For detection of antibodies, the OIE recommendations are to

combine ELISA with other tests such as fluorescent antibody tests or the indirect immunoperoxidase test (Gallardo et al., 2015);OIE, 2012). In endemic areas, antibody detection can be of epidemiological value. In such cases it is recommended to combine antibody detection with detection of viral genome by PCR (OIE, 2012).

CHAPTER THREE: GENERAL METHODOLOGY

3.1 Study context

3.1.1 Study area

This study was conducted in four of the 16 subregions in northern, eastern, central and western Uganda (Figure 3.1). Specifically, the subregions of Acholi and West-Nile in Northern region, Buganda in Central region, and Kigezi in Western region.

For specific objective one, greater Gulu in Acholi subregion was chosen due to its characteristic elements such as post-conflict vulnerability (Finnström, 2008), and poverty rates below the national level (Okidi & McKay, 2003; UBOS, 2021b). In addition, the endemic situation of ASF in greater Gulu (Muhangi et al., 2015; Chenais et al., 2015; Chenais et al., 2017c), made it a suitable region for the study on ASF. Greater Gulu comprises of four District Local Governments including one city.

Specific objective two was implemented in Buganda subregion, investigating ASF outbreaks in an intensive farm. Most of the modern pig farms in Uganda are found in this region (Twine & Njehu, 2020). This study investigated two ASF outbreaks (2021 and 2022 waves) which occurred in a commercial large-scale modern pig farm with well-established biosecurity protocol.

For specific objective three and four, two districts, one in Kisoro (Kigezi subregion) and Moyo in (West-Nile subregion), were targeted due to quarantine impositions in those two districts. Both districts are sharing international borders with Republic of Rwanda and Democratic Republic of Congo (DRC) (for Kigezi), and Republic of South Sudan (SS) and DRC (for West-Nile). The porous nature of these international borders facilitates unregulated cross border movement of pigs and pig products. Over 95% of pigs slaughtered in the West Nile subregion are sourced from neighboring districts (Muhangi et al., 2014).

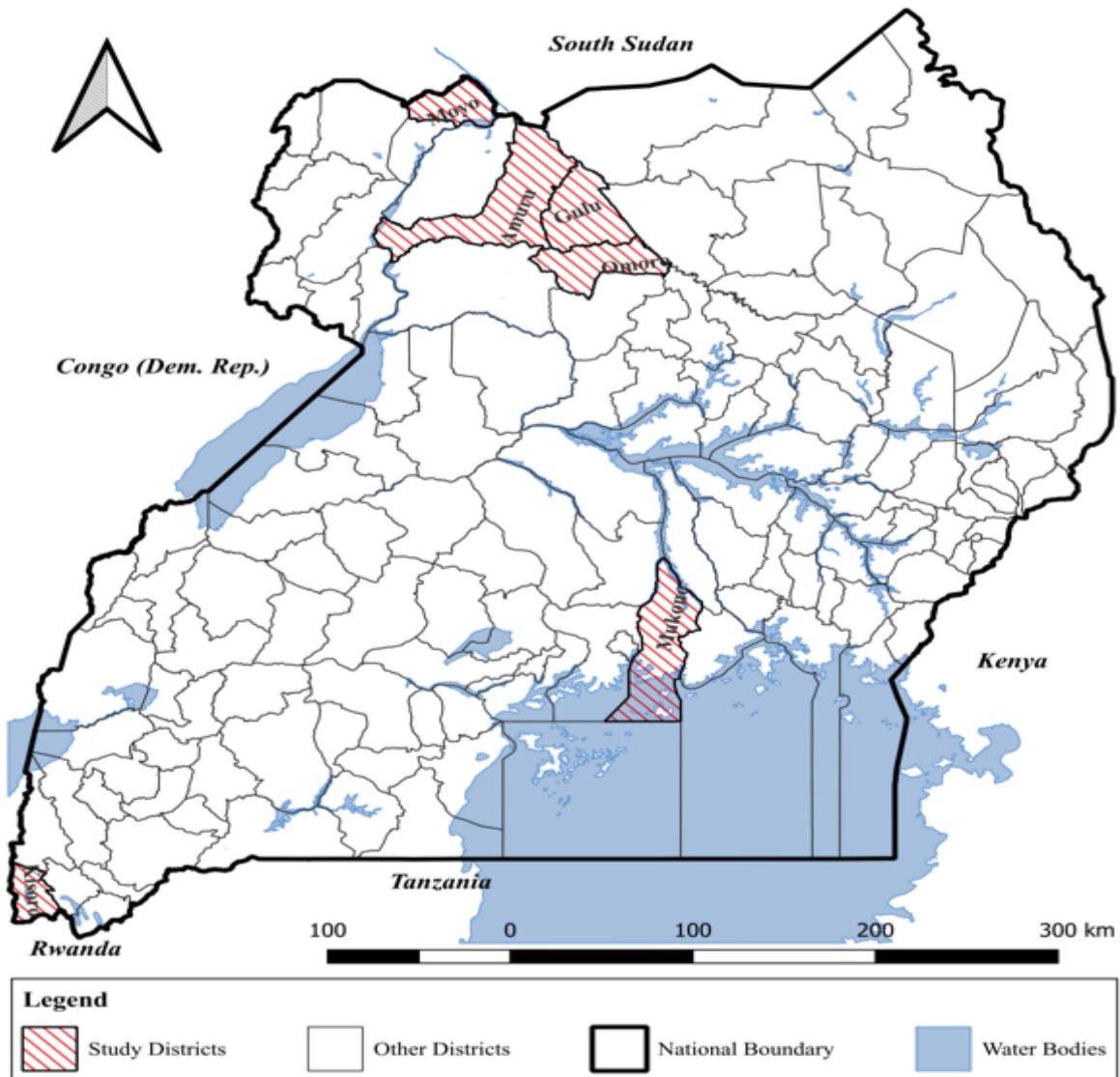


Figure 3.1: Map of Uganda showing study locations (source of this map?)

3.1.2 Research design

This study applied both qualitative and quantitative research approaches to achieve the four specific research objectives, while considering primary data collected from a cross-section of pig stakeholders in northern and western Uganda, and a modern pig farm in central Uganda. Summaries of methods applied for each objective are presented in Table 1.2. The detailed explanation of research methods used for each research objective are found in the corresponding specific chapters.

The first Objective (O1, Chapter 4) used a qualitative approach. This study involved 66 stakeholders from Amuru, Gulu, and Omoro districts. Primary data from stakeholders were collected through six focus group discussion (FGDs) meetings, see guiding questions in

Appendix 2.1. The focus of the data collection in this paper was perceptions of the existing biosecurity measures in use. Thematic analysis was used to analyze the data, see Appendix 2.2.

The second objective (O2, Chapter 5) was quantitative in nature and involved laboratory results from 1,121 pigs suspected of suffering from ASF in year 2021 and again from 241 suspected ASF cases in year 2022, all from this study farm in Wakiso. Primary and secondary data were collected from company owners and employees with focus on descriptive history of outbreaks and farm records of morbidity and mortality. In this paper, focus was on assessing sample results from dead, sick and in-contact pigs during two waves of ASF outbreaks at the farm. Sixty pig feeds samples were collected from farm's feed store in 2022. Testing of the samples for ASFV were done at the molecular biology laboratory at the Makerere University, College of Natural Sciences (CoNAS). The disease investigation approaches applied were descriptive statistics (e.g. *epidemic curve*, *line list* presented as a table summarizing the information about persons/individuals associated with the outbreaks), routine data analysis such as total counts (number of pigs before ASF outbreak, mortalities and survivors), total number of samples tested and total number positive, and univariate analysis for most affected age groups.

The third objective (O3, Chapter 6) used a qualitative approach involving 77 stakeholders and two district veterinary officers (DVOs) in the districts of Kisoro (n=1) and Moyo (n=1). Primary data were collected from stakeholders through 10 FGD meetings and two key informant interviews (KIIs) with the respective DVOs, see guiding questions in Appendix 4.1 and 4.2. Data collection was on perception of implementation and cost implication of the imposed quarantine measures. Descriptive statistical analysis was used to assess actions taken and perceived economic effect of quarantine imposition among pig stakeholders.

The fourth objective (O4, Chapter 7) was quantitative in nature and involved 14 core participants (pig stakeholders) from Moyo district and a reference-group composed of five technical experts of different specialty from Gulu University (1), MAAIF (1), and Moyo district local government (3). During day one and two of a workshop in Moyo district, primary data was generated by core participant through participatory group model building (GMB) approach of SD. Cost implication associated with quarantine imposition identified in article three, especially from Moyo district, formed a basis for implementing GMB. SD sensitivity analysis was applied, and data formed the basis for implementing a participatory GMB approach to parameterize a SD-model of the pig value chain for scenario analysis. This involved guided

discussions to jointly develop models, generate parameters, and validate output of model simulation.

Table 3.1: *Summary of methods used*

	Chapter	Sample		Data collection method	Data Analysis approach
4	Perception of ASF prevention and control measures among smallholder pig farmers	66 stakeholders	Primary data from Amuru, Gulu, & Omoro	FGDs and KIIs	Thematic analysis
5	Investigation of ASF outbreaks in a modern commercial pig farm	1 farm	Case study with primary and secondary data from Mukono	Observations, record investigation, interviews	Descriptive statistics, routine data analysis of reports
6	Actions and the perceived economic impact of ASF control measure	79 stakeholders	Primary data from Kisoro & Moyo	FGDs and KIIs	Descriptive statical analysis
7	Assessing the economic impact of ASF-induced quarantine imposition in smallholder pig value chains – a system dynamics approach	14 Core participants (stakeholders) Five members of reference group	Primary data from Moyo	Participatory GMB in SD	Scenario analysis & Validation

3.2 Ethical considerations

This study was conducted with PVC actors and a modern pig farm in Uganda with focus on value chain actors and live pigs. Biological samples were collected from pigs, but not from humans being. All the codes of conduct regarding legal and ethical guidance in research were followed accordingly. First, the District Veterinary Office involved during the study, are mandated by MAAIF to investigate animal disease in Uganda. Furthermore, the veterinarian involved in collection biological samples is a legally registered member of Uganda Veterinary Board. Secondly, the study was approved by the Gulu University Research Ethic Committee (GUREC) (GUREC-056-19) and the Uganda National Council of Science and Technology

(UNCST). Thirdly, the study had other ethical approvals granted by Ugandan National Council for Science and Technology under the reference number A497, and by the School of Health Sciences Research and Ethics Committee, Makerere University, Kampala, reference number 2019–062. Lastly, informed consent was obtained from all selected participants, and only those who voluntarily consented to participation were interviewed. Those who declined were substituted by another willing participant.

CHAPTER FOUR: PERCEPTION OF ASF PREVENTION AND CONTROL MEASURES AMONG SMALLHOLDER PIG FARMERS

This chapter provides highlights the perception of ASF biosecurity implementation in the smallholder pig value chain in Northern Uganda. The chapter was guided by the following research questions

1. What are the existing biosecurity measures being used in the smallholder pig value chain?
2. What are the reasons for poor implementation of existing biosecurity measures by smallholder pig value chain stakeholders?
3. Which existing biosecurity measures are feasible to implement by smallholder pig value chain stakeholders?

This chapter has resulted into:

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. *Frontiers in Veterinary Science*, 8 (January). <https://doi.org/10.3389/fvets.2021.707819>.

4.1 Introduction

In Uganda, ASF outbreaks in domestic pig population have been shown to have negative impact for smallholder farmers, with economic consequences increasing with the herd size and social effects such as failure to pay for school or public health fees being reported (Chenais et al., 2017b; Chenais et al., 2017c; Kabuuka et al., 2014; Ouma et al., 2018). Transmission of ASF mainly occurs through direct and indirect contacts between naïve and infected pigs or products in the domestic pig-to-pig epidemiological cycle (Penrith et al., 2013). In this cycle transmission further depends on the activities of people along the value chain (farmers, traders or middlemen, slaughter slab operators, butchers, pork restaurant operators and consumers), thus all these actors are important for achieving disease control (Muhangi et al., 2014; Rich & Perry, 2011). Consistent application of biosecurity measures remains the only tool for preventing and controlling ASF (FAO, 2010b; Penrith, 2020). In typical smallholder systems farm biosecurity is however generally limited or non-existent (Costard et al., 2009b; Fasina et al., 2012b; Dione et al., 2015a; Leslie et al., 2015b).

Previous studies in northern Uganda revealed that smallholder farmers have mostly positive attitudes towards the protective potential of biosecurity (Chenais et al., 2017c; Chenais et al., 2019a), but invest very little of their pig farming income into it (Kabuuka et al., 2014). Studies from both this and other contexts have further shown that smallholder farmers have complex livelihood situations with biosecurity representing just one of numerous concerns in their livestock production (Chenais et al., 2019a; Chenais et al., 2021). To prevent and control ASF, more information is needed about how implementation of biosecurity can be improved throughout the value chains. As a first step, this chapter aimed to explore biosecurity measures currently in use in the smallholder pig value chain in northern Uganda with a particular focus on the stakeholders' perceptions towards ASF prevention and control.

4.2 Materials and methods

4.2.1 Study area

The study was conducted in Amuru, Gulu and Omoro districts of Northern Uganda, Figure 4.1. The subregion is among the poorest in Uganda, partly due to a period of civil unrest between 1986 and 2006 (Branch, 2013). The Acholi people traditionally keep domestic animals both for livelihood requirement and as a part of their cultural identity (Hewlett & Hewlett, 2008). According to the Acholi cultural tradition, lack of respect for spirits is the major cause of

“*gemo*” (epidemics). Many of the Acholi were internally displaced and lost their domestic animals during the period of civil unrest. Since 2006 the subregion is under a government recovery program including restocking to promote livestock including pig farming. Despite frequent ASF outbreaks subsistence of smallholder pig farming has become a major economic activity in the sub-region (Chenais et al., 2015).

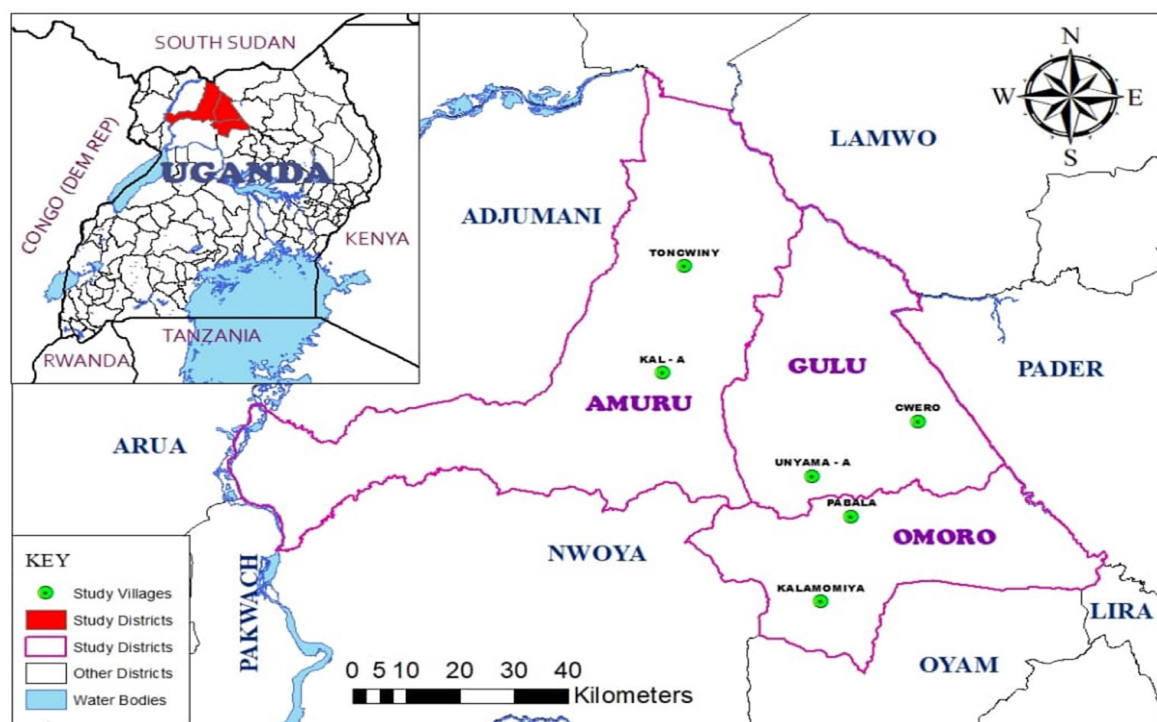


Figure 4.1: Map showing the study districts, highlighted in purple color

4.2.2 Study design and sampling

A cross-sectional study design was used. In a qualitative interview study performed in October 2019 focus group discussions (FGD) were conducted to assess biosecurity measures currently used and elicit stakeholders’ perception of ASF prevention and control. In the context of this study the term “perceptions” included aspects such as the practical feasibility, factors enabling or hindering implementation, and perceived protective effect of disease prevention and control measures.

Three districts were purposively selected based on the relative importance of pig business and from each of these two villages were included (Unyama-A and Cwero in Gulu district; Pabala and Kalamomiya in Omoro district; and Toncwiny and Kal-A in Amuru district) (Figure 2.1). Inclusion of villages was primarily based on field information of suspected ASF occurrence

and farmers' preliminary perceived interest in ASF control. Field information of ASF occurrence consisted of outbreak reports from district veterinary officers consistent with ASF based on clinical signs and local epidemiology. Reports were not confirmed with biological testing; based on previous participatory diseases surveillance and absence of main differential diagnoses for ASF the diagnostic accuracy of the reports was deemed sufficient for the purpose of this study according to Chenais et al. (2015). Participants preliminary perceived interest in ASF control was based on information from district veterinary officer and confirmed or refuted during the recruitment process. Further, the availability of a suitable number (Penrith et al., 2013; Chenais et al., 2015; Dixon et al., 2005; Sánchez-Vizcaíno et al., 2015; Gallardo et al., 2017) of pig farmers for the purpose of a group discussion and known presence of several different actors along the value chain such as middlemen, slaughter slab operators, butchers, and pork joint owners were considered in the selection. Farm or herd size was not among the inclusion criteria. Previous studies in the area showed that pig production is almost exclusively performed by smallholder farmers with herd sizes ranging from 0 to 39 with an average of 3.7 pigs including piglets (Kabuuka et al., 2014). Villages were selected by the first author in consultation with the district veterinary officers of each district. One FGD was held in each of the selected villages, hereafter identified as FGD 1 in Unyama-A village, FGD 2 in Kalamomiya village, FGD 3 in Pabala village, FGD 4 in Cwero village, FGD 5 in Kal-A village, and FGD 6 in Toncwiny village.

The number of villages selected was based on the presumed number of FGDs needed to reach saturation. Participants for each FGD were further purposively selected with the intention to include as many different value chains actors as possible, and to have an equitable gender representation (Table 4.1). The purpose of the aspired group heterogeneity was to include a wide array of different experiences and perspectives. Participants were invited by the community animal health workers in the selected villages based on the mentioned inclusion criteria. The FGDs were conducted at venues that were convenient for participants, such as in community trading centers, sub-county headquarters, schools, health centers or the home of one of the participants. There were on average 11 participants per FGD, and the FGDs lasted on average 5 h 13 min (ranging from 4 h 20 min to 5 h 50 min), including a lunch break. Participants were compensated for their transport costs and lunch was provided in connection with the interview.

4.2.3 Data collection

The research team was composed of a facilitator (TA), a senior researcher (EC), and a translator proficient in both the local language (Acholi) and English. Both the facilitator and the translator had been trained in qualitative research approaches and the procedure for data collection prior to the study. The FGDs started with the facilitator introducing the purpose of the study, specifically emphasizing that it was research and not a needs assessment or similar with possible immediate benefits for participants. It was explained that participation was voluntarily. Confidentiality was assured and permission sought to take photographs and make voice recordings, and participants signed a written consent form to this effect. The discussions which started with farmers' experience of ASF outbreaks (Table 4.2) were conducted in Acholi and simultaneously translated and recorded. Detailed notes were taken during the FGDs, and the recordings were subsequently transcribed verbatim. Discussions followed a topic guide (see Appendix 4.1) centered on the measures that participants had implemented to prevent ASF outbreaks and control the spread of ASF during outbreaks. The facilitator guided the discussion according to the topic guide, while letting participants lead the discussion to subjects that were important to them.

4.2.4 Data analysis

The field notes and transcripts of the audiotapes were merged to form one master set of notes for each FGD. In a first step, all mentions concerning biosecurity were identified (Table 4.3). Secondly, thematic analysis was applied to the master notes (Braun et al., 2008). This was done independently by two of the authors (Tonny Aliro and Daniel Michael Okello). In this step, every segment of the data relevant to perceptions of prevention and control were coded to represent the initial stage in the conceptualization of the transcribed data. These primary codes were allowed to emerge inductively through repeated reading of the data, while forming hypotheses about the data that were subsequently refined in repeated rounds of analysis, comparing and merging the two sets of codes (LeCompte, 2000). Applying axial coding, TA and DMO together sorted the primary codes into common themes (Moghaddam, 2006)(see Appendix 4.2). Finally, TA combined themes associated with others to form six categories. The themes and categories are summarized in a matrix (Table 2.4) for ease of traceability back to the original data, to provide the relationship between the themes and the FGDs and to illustrate the frequency of mentions (Goulding & Goulding, 1999). The emerging categories,

their internal relation, additive inference for ASF prevention and control, and a suggestion for improving implementation of biosecurity was visualized in a logical framework (Figure 4.2).

4.3 Results

4.3.1 Participant characteristics

A total of 65 participants (between nine and twelve per FGD) were included in the six FGDs (Table 4.1). Out of these, 48 were purely pig farmers and 17 were involved in different business along the value chain (some of these participants also kept pigs but did not consider pig farming their main occupation). Pig farmers had between three and six pigs each.

Table 4.1: Distributions of FGDs participants, their roles and gender

FGD/value chain role	Value chain roles														Total No. of participants
	Pure farmer		Trader & butcher		Trader, butcher, & pork join own		Trader and pork joint owner		Farmers butcher, & pork join own		Farmer, trader, butcher and pork joint owner		Purely Pork joint owner		
Gender	M	F	M	F	M	F	M	F	M	F	M	F	M	F	
FGD-1	4	4							1						9
FGD-2	4	4							3				1		12
FGD-3	7	2			1						1	1			12
FGD-4	5	3							1	1					10
FGD-5	6	2	2				1								11
FGD-6	5	3	1			3									12
	31	18	3		1	3	1		5	1	1	1	1		66

4.3.2 Experience of ASF outbreaks

Recent ASF outbreaks were mentioned to have occurred in the months of April, May, June, August and October 2019, during both dry and wet season (Table 4.2). Sudden death, change in body color displayed as red ears and hooves, reduced appetite, difficulty in walking and dullness were each mentioned by at least two FGDs as clinical signs suggestive of ASF. FGDs 2, 4, and 5 reported massive pig deaths as the determinant sign of ASF.

Table 4.2: Details of recent African swine fever outbreak from a study conducted in October 2019

Groups	Last occurrence	Participants' comments
FGD-1	April 2019	Common during cold weather, dry spell and beginning of rain.
FGD-2	June 2019	Serious during sunshine, and heavy rain season
FGD-3	May 2019, October 2019	Common during bad hot weather and rainy season
FGD-4	May/June 2019	During dry spell and in December when it is hot. When it's hot and a lot of wind
FGD-5	April/May 2019	When the rain starts every year. Comes during dry spell with sunshine and dust
FGD-6	April/June/August/2019	Outbreaks are always during dry season

4.3.3 ASF biosecurity measures

During the FGDs, 20 different biosecurity measures were mentioned. Many of these were similar and seven groups of more general biosecurity or husbandry measures could be identified (Table 4.3).

Table 4.3: African swine fever biosecurity measures mentioned

Mentions of biosecurity
General hygiene practices: good hygiene practices, use of disinfectant, do not use the same equipment for pigs and at home
Minimising indirect contacts: Few attendants allowed in the pig house, non-attendants do not enter the pig house
Minimising direct pig-to-pig contacts: Build pig house, fence pig house, confinement of free-range pigs, tether pigs, stray pigs should not enter the pig house, do not borrow boars
Feed and water of good quality and sufficient quantity: Provide feed, avoid swill feeding, provide enough water
Safe carcass handling: Bury or burn carcasses
Restriction of trade in pigs and products: Don't bring pork home, stop buying pigs during outbreaks
Sharing of pig health information: Alert neighbors during outbreak, call veterinary personnel
Other: Remain close to pigs all the time

4.3.4 Thematic analysis of perceptions of ASF prevention and control

During the thematic analysis, 39 themes were identified from the emerging primary codes. The themes were summarized into six categories (Table 4.4 and Appendix 4.2). The categories included “ASF biosecurity measures perceived as effective,” “local knowledge of ASF transmission,” “implementation of biosecurity is partially hindered by its cost,” “priority given to livelihoods,” “local culture and traditions,” and “access and quality of veterinary services.” Narrative details of themes and categories are explored below.

Table 4.4: Perception of ASF prevention and control among pig value chain actors

Categories and themes/FGD/Number of mentions	FGD 1	FGD 2	FGD 3	FGD 4	FGD 5	FGD 6	Total No mentioned
ASF biosecurity measures perceived as effective							
Pig can be confined in houses or by fences, and these can be constructed in different ways	✓	✓	✓	✗	✗	✗	3
Confining pigs prevent contact with other pigs and people	✓	✓	✓	✗	✗	✗	3
Restrict pigs' movement to control what the pigs eat and avoid contacts with sick stray pigs and contaminated items	✓	✓	✓	✓	✓	✓	6
Disclosing animal health status	✗	✗	✗	✓	✓	✗	2
Implementation of local punitive measure	✓	✗	✗	✗	✗	✗	1
Local knowledge of ASF transmission							
ASFV can be transmitted by the wind	✓	✓	✓	✓	✓	✓	6
Damp ASFV cannot be blown from carcasses dumped in the swamp	✓	✓	✗	✗	✗	✗	2
Flies and wind can carry infective materials	✓	✓	✓	✓	✓	✓	6
Dogs, pigs and people can bring contaminated pork or bone	✓	✓	✓	✓	✓	✓	6
Feed and water contaminated with urine, faeces and saliva	✓	✓	✓	✓	✓	✓	6
People contaminated with faeces and blood	✓	✓	✓	✓	✓	✓	6
Borrowing breeding boars for mating	✗	✗	✓	✓	✓	✓	4
Contaminated unwashed hands handling feed and pigs	✗	✗	✓	✗	✓	✗	2
Use of contaminated utensils, farm tools and protective gear	✗	✗	✗	✓	✓	✗	2
Middlemen and slaughterers can transmit disease	✓	✓	✓	✓	✓	✓	6
Trade in live pigs can transmit disease	✓	✓	✓	✓	✓	✓	6
Vets can transmit disease	✗	✗	✗	✓	✗	✗	1
Cool temperatures protect pigs, heat kills ASFV	✓	✓	✗	✗	✗	✗	2
Disinfection using ash and "jik"	✗	✗	✓	✓	✓	✗	3
Basic hygiene	✗	✗	✓	✗	✓	✗	2
IMO technology adoption	✗	✗	✗	✗	✓	✗	1
Leaving farm tools and protective gear at the pig stables	✗	✓	✓	✗	✓	✗	3
Isolating sick or relocating healthy pigs	✗	✓	✗	✗	✓	✓	3
Feed quality and quantity is important for good health and fast growth	✗	✓	✓	✗	✗	✗	2
Implementation of biosecurity hindered by cost							
Disinfectants, cleaning materials, building materials, fuel and feeds are unaffordable	✓	✓	✓	✓	✓	✓	6
Priority given to livelihoods							
Carcasses are consumed at home, sold to raise some money and avoid total losses	✓	✓	✓	✓	✓	✓	6
Trade in live pigs to protect healthy ones, raise some money and avoid total losses	✗	✓	✓	✗	✓	✓	4
People bring pork home to eat	✓	✓	✓	✓	✓	✓	6
Butchers and middlemen make a profit during outbreaks	✓	✓	✓	✓	✓	✓	6
Selling sick pigs poses risk of ASF spread	✓	✓	✓	✓	✓	✓	6
Local culture and traditions							
Burial of animals is forbidden in the Acholi culture and tradition	✗	✗	✓	✓	✓	✓	4
It is hard to dig a grave	✗	✗	✗	✗	✓	✗	1
It is psychologically painful because it reminds you of burying loved ones	✗	✗	✗	✓	✗	✓	2

People can throw bones, pork, and intestine in the pigsty to intentionally infect healthy pigs	x	✓	✓	✓	✓	✓	5
Access and quality of veterinary services							
Smallholder farmers have access to veterinarians	✓	x	✓	✓	✓	✓	5
Smallholder farmers do not have access to veterinarians	✓	✓	✓	✓	x	x	4
Veterinary treatments are helping	✓	x	✓	✓	x	✓	4
Veterinary treatments are not helping		✓	✓	✓	✓	x	6
There is no medicine or vaccine for ASF	x	✓	✓	✓	✓	✓	5

4.3.4.1 ASF biosecurity measures perceived as effective

Biosecurity measures were generally perceived positively by participants. Construction of pigsties or fences were often mentioned as helpful for preventing contact between confined and free-range pigs, and with people. Participants in all FGDs stated that confined pigs are protected from coming into contact with infective materials such as bone and pork or contaminated water in the environment: “*Pigs confined in the pigsty survived; pigs that were released to be on free range contracted ASF and all died*” (FGD 3). Sharing information about ASF outbreaks was also seen as helpful, serving to alert farmers to improve biosecurity measures and to take protective measures if, for example, pork was brought home for consumption. Farm-gate buying and selling of live pigs was mentioned as a common practice. Participants in one FGD said that they would welcome stricter implementation of punitive measures set locally to improve biosecurity, such as obligatory confinement of pigs and trade restrictions concerning live pigs and pork if outbreaks have been recorded in the area. In this regard, participants said that people did not fully comply with existing by-laws: “*Some people follow the rules, but others don’t*” (FGD 1).

4.3.4.2 Local knowledge of ASF transmission

Participants in all FGDs believed that airborne transmission of ASFV could occur if the virus from infective tissues or ashes from burned carcasses was carried by wind. Similarly, participants stated that flies can be contaminated with ASFV while feeding on infective materials and then transmit the virus to feed or water, which in turn can infect healthy pigs. In all FGDs, participants mentioned that vegetables and water could be contaminated with saliva, feces or urine from infected stray pigs and serve as a source of infection if served to healthy, confined pigs. Participants further said that feces and urine excreted by infected confined pigs could contaminate feed left on the floor or in the feed trough. It was mentioned that infective remains of partly burned carcasses could be eaten by free-range pigs. In this regard, participants also said that pigs could dig up carcasses if they were not properly buried. In some FGDs,

participants said that people who buy and bring pork home could infect healthy free-roaming pigs if bones were not discarded out of the pigs' reach.

Participants in all FGDs mentioned that confined pigs could become infected if butchers and middlemen wearing blood-stained clothes were allowed to enter the enclosure and touch pigs before purchase: *"Farmers would see money and just let the butcher enter the pigsty"* (FGD 2). Participants further said that stray boars that enter pigsties (either on their own or being driven into the house) to mate with sows could transmit ASFV. In some FGDs participants said that ASF transmission could occur if people who had handled infected pork subsequently handled pig feeds without first washing their hands. Likewise, they said that saucepans used to carry pork from the market and subsequently used to water pigs without prior washing could transmit ASF. They also described how ASF could be transmitted if the same wheelbarrow was used to carry contaminated maize from the fields and for pig feeds. Having clothes, gumboots and wheelbarrows strictly for use in the pigsty was mentioned as a good practice that could stop the spread of ASF. The practice of disinfecting shoes at the door and washing hands before entering the pig house would still leave other body parts contaminated: *"Chemicals will kill the virus on gumboots and shoes, but not on hair or clothes"* (FGD 3).

Avoiding purchasing pigs during ASF outbreaks was mentioned as a way of preventing disease transmission because sick or in-contact pigs are frequently marketed: *"Farmers sell sick pigs cheaply without disclosing their health status to buyers"* and *"Buyers know sick pigs by their low price"* (both FGD 3).

Participants mentioned "cool temperature" as one factor that could influence ASF transmission. According to their described experience, healthy pigs that were relocated to swampy areas during an ASF outbreak would not die. Meanwhile, sick pigs left on the farm would die of the fever, accelerated in their view, by high temperatures in the pigsty. They further described how the wind would not transmit ASFV from carcasses if they were dumped in swampy areas: *"It is better to throw it in the water so that the virus is not blown by the wind"* (FGD 5). Farmers noted that staying close to pigs to immediately remove feces could serve to maintain good hygiene, and that this could prevent the spread of ASF. Participants in one FGD mentioned that adoption of indigenous microorganism (IMO) technology for floor bedding (using rice bran) in pigsties could decompose feces and urine, serving the same purpose. Participants also said that the isolation of sick pigs prevented healthy pigs from succumbing to ASF. Among the different modes of isolation, participants mentioned transferring healthy pigs to disease-free

villages. Provision of good-quality feeds in sufficient quantity was mentioned as boosting the immunity of pigs and stimulating fast growth. The latter was specifically said to be useful for getting pigs to market size before the onset of anticipated ASF outbreaks, as pigs grow faster and are sold before the predictable outbreak strikes. All FGDs mentioned that ASF outbreaks occur throughout the year: *“We believe that it is brought by hot weather”* and *“If it is serious sunshine, the outbreaks get serious”* (both FGD 2).

4.3.4.3 Implementation of biosecurity is partially hindered by its cost

Participants revealed that many community members could not afford to buy pig feeds or disinfectants. In addition, commercial feeds such as maize and rice bran were mentioned as being difficult to access. Farmers who could not afford to buy feed said that they let pigs roam free to scavenge, and that supplementary feeding was done using swill collected for free from restaurants or home kitchens. Participants frequently mentioned that it would be too costly to use fuel such as petrol which can burn carcasses to ash, and that dead pigs need to be marketed (and not destroyed) to recover as much of the incurred losses as possible. Some farmers mentioned that they manage to prioritize investing in biosecurity and buying materials for constructing and cleaning the pigsty.

4.3.4.4 Priority given to livelihoods

Participants said that they slaughtered sick pigs for home consumption, sold pork from pigs that had died to neighboring communities to raise money, and used pork to barter for other food items as a way of coping with the hardship experienced during ASF outbreaks: *“When you have a pig sick with ASF and don’t want others to know, you slaughter it and sell it quickly, and say that the pig was strangled by the tethering rope”* (FGD 4). Participants also said that sick pigs were sold to protect the health of the remaining pigs, to raise money and to avoid the total loss of investments that would occur if the pigs succumbed to ASF. Healthy pigs that had been in contact with suspected ASF cases were reportedly sold for the same reasons and with the aim to use the earnings to restock pigs after the outbreak. As pork is cheaper than usual during outbreaks, participants said that people would take these opportunities to buy pork and bring it home for family consumption or go to eat at places such as pork joints and hotels (FGD 2). Participants further reported that whenever pigs are slaughtered, neighbors not rearing pigs might buy pork and take it home to eat. Farmers reported that middlemen and butchers would buy pigs (sick and healthy) at a low price during ASF outbreaks but maintain the regular sale

price for both fresh and cooked/roasted pork, thus taking advantage of a low buying price to make more profit.

4.3.4.5 Local culture and traditions

Participants in several FGDs mentioned that, according to the Acholi culture and tradition, the burial of animals is forbidden. They said that if animals were buried, other animals would die. In some FGDs, participants said that all animals except dogs could be buried without there being bad consequences, whereas burying dogs would be associated with the disappearance of rain for a year. Apart from the cultural taboo related to the actual act of burying animal carcasses, frequent mention was made of contextual constraints regarding throwing away food, and in particular meat, in the poor study communities. Repeated mention was also made of people possibly digging up buried carcasses to get access to the meat. In addition, they said that burying animals is painful because it reminds them of burying loved ones. The hard work required to dig a hole deep enough to prevent carcasses being exhumed by animals or people was mentioned as discouraging the implementation of this practice for safe carcass disposal. All FGDs mentioned that people (in most cases neighbors) sometimes threw bones, pork or intestine in other peoples' compounds to infect pigs deliberately out of jealousy. This was exemplified as follows: "Poisoning of pigs in our area by people who are jealous has become a culture" (FGD 4) and "When I saw somebody dropping pig bones in my pigsty, I was furious. I immediately let all the pigs out, and they all ran to the swampy area. Some pigs died; others survived" (FGD 3).

4.3.4.6 Access and quality of veterinary services

Smallholder farmers in four FGDs expressed their trust in local veterinarians for the diagnosis of ASF as well as for giving advice on disinfection procedures and other prevention practices. In the study area, veterinarians qualified to diagnose and treat animals can be either employed by the government or private. Participants mentioned that veterinarians were generally available, and they were praised for giving advice to farmers on how to manage pig health during outbreaks. However, three FGDs had generally negative accounts, mentioning that veterinarians frequently either did not respond to farmers' calls, or responded so late that all the pigs they treated ended up dying: "Veterinarians say there are no drugs, so won't respond to farmers' calls" (FGD 4). The negative accounts further included mention of veterinarians offering generally bad services and giving false expectations about the survival possibilities of

ASF infected pigs if treated: “Veterinarians injected pigs, the medicine didn’t work, all the treated pigs died” (FGD 5). In this regard they also mentioned some veterinarians asking for payment from farmers for treatment, even if there is no hope of saving the pigs. In one FGD, farmers noted that veterinarians could play a role in transmitting ASF as they reuse needles between different herds. These accounts also included complaints about veterinarians not making farmers aware of the dangers of ASF.

Participants in five FGDs mentioned that they had no hope of saving the lives of pigs infected with ASF, and that the disease has no treatment or vaccine, unlike other pig diseases that can be cured if sick pigs are treated: “Farmers vaccinate pigs against other diseases such as flu and worms” (FGD 4), “The vaccination has no effect on ASF” (FGD 2). Farmers said that they do not call veterinarians to treat pigs for ASF as there is no cure for it: “Veterinarians would say there is no drug for ASF, so they would not come to treat it” and “It’s not easy, some pigs could still die even if the vet treated them” (FGD 3).

4.3.5 Logical framework

The emerging categories encompassed both “enablers” and “hindrances” for ASF prevention and control (Figure 4.2). Participants mostly had positive perceptions of ASF biosecurity, describing many measures as feasible to implement and effective for preventing or controlling ASF outbreaks. Together with rich local knowledge of ASF transmission this enabled prevention and control of ASF. Some of the knowledge corresponded to current scientific understanding and practices and some not. Misbeliefs regarding aerial (air-borne) transmission or virus survival in ash might hamper effective implementation of biosecurity, whereas knowledge regarding transmission via direct and indirect contacts facilitated achieving control. Four categories were seen as hindrances. Participants’ efforts to implement ASF prevention and control measures were limited by: biosecurity costs such as building material and pig feeds that is necessary if pigs are to be confined; the need to prioritize family livelihood over known disease transmission risks connected to for example trade in sick pigs or carcasses from pigs that have died from disease that could be ASF; local culture, traditions and social factors that such as complicated safe destruction of carcasses; and finally lack of access to veterinarians or, occasionally, due to low-quality veterinary services. Together this often resulted in failed biosecurity, with the main hindrances seemingly being the cost of the measures, and to some extent the incompatibility of current biosecurity practices with local traditions, context and culture. Both these constraints could be addressed by adapting biosecurity measures to local

cultural, social and economic contexts in a participatory process involving the concerned end users.

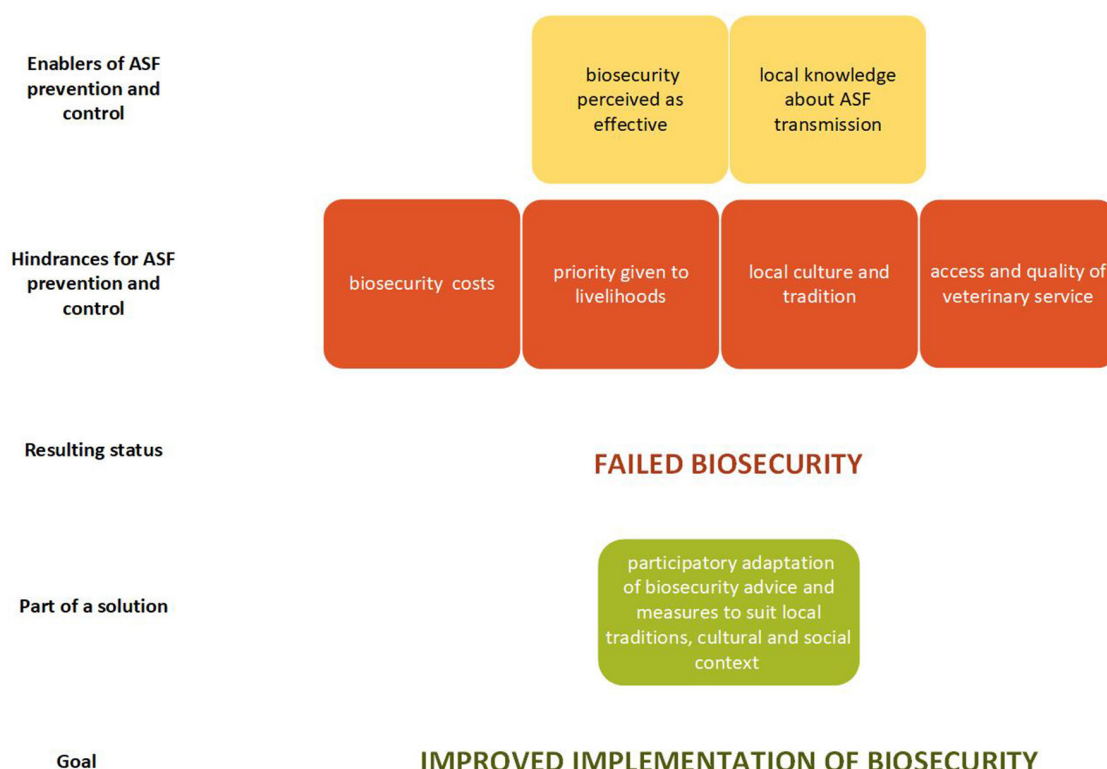


Figure 4.2: Logical framework illustrating the results from the study

4.4 Discussions

This study demonstrated that despite mostly positive perceptions of ASF biosecurity, biosecurity measures were not being implemented due to costs of feed and housing, and the fact that family livelihood had to be prioritized over investments in disease control. Other hindrances were limitation in veterinary access and quality of services, and biosecurity measures that were not adapted to local culture and traditions.

This study showed that perceptions of biosecurity in the smallholder pig value chain in northern Uganda were mostly positive, especially regarding the preventive effect of rather simple measures such as confining pigs and not buying pork during outbreaks. The study did not seek to assess participants' knowledge of ASF but still captured rich accounts of local knowledge about ASF transmission. It therefore appeared as if neither participants' perception of biosecurity nor their knowledge were the main limiting factors for implementation of ASF biosecurity, in accordance with previous studies from similar settings in Uganda (Chenais et al., 2017b; Dione et al., 2020a).

Health behaviour model have been used to describe and increase the understanding of people's behaviour and decision making in relation to their own or their animals health or disease risks (Corner & Norman, 2009). Many such models refer to social cognitive behavioral theory to explain behavior and decision making, in short attributing the factors determining behavior to the characteristics of the individuals and their social networks (Conner & Norman, 2005; Conner & Sparks, 2009; Schemann et al., 2013; Schemann et al., 2012). The categories emerging as enablers of implementation of biosecurity in this study ("ASF biosecurity measures perceived as effective" and "local knowledge of ASF transmission") could be considered as social cognitive factors, relating to beliefs, attitudes or knowledge (Cummings et al., 1980). Categories hindering implementation of biosecurity ("implementation of biosecurity is partially hindered by its cost," "priority given to livelihoods," "local culture and traditions," and "access and quality of veterinary services") however, were linked to contextual and social factors (Ebata et al., 2020a).

Ebata et al., (2020a) describe how such contextual factors can make compliance difficult or even impossible for local people. According to the results, costs of constructing houses or enclosures and providing feed if pigs are prevented from scavenging were in many cases perceived as unaffordable and could thus not be implemented despite the positive perceptions of these measures. Similar reasons for the failure to implement the most basic biosecurity measures necessary for minimizing direct and indirect contacts have previously been reported (Fasina et al., 2012a; Ouma et al., 2018; Dione et al., 2020). Likewise, minimal investments in pig feeds have previously been reported from the same area (Kabuuka et al., 2014), with pig diets consisting of vegetables, cassava peelings and swill, or pigs scavenging for food. Swill feeding, which is continuously practiced as a way of reducing feed costs, is a risk factor for ASF management, especially in endemic areas (Fasina et al., 2012b; Nantima et al., 2015a; Chenais et al., 2017b).

Affordability of inputs and measures that are developed and adapted with end users, thus ensuring suitability and local acceptance, have been suggested as key to achieving functional biosecurity (Penrith et al., 2021a). The term "functional biosecurity" is used here to indicate that it is the operational end-result of the total biosecurity efforts, that sufficient biosecurity is always implemented at all risk activities, that is the most important aspect of biosecurity. The opposite, failed biosecurity, have been attributed to lack of biosecurity routines or equipment

(biosecurity hardware), or routines that are prescribed but not implemented (biosecurity software) (Chenais et al., 2019b).

Providing for the family livelihood and sustaining income were clear priorities for the participants, overriding other concerns such as the risk of transmitting disease or not complying with regulations such as trade restrictions in connection with ASF outbreaks. The high poverty levels in the study area, among the highest in Uganda (UBOS, 2019), most probably contribute to the priority given to sustaining income. In the study area, pigs are mostly not kept for household consumption, but mainly to provide money for school fees or unforeseen healthcare events, and to barter for agricultural labor (Kabuuka et al., 2014). Consequently, the sale and slaughter of clinically sick or in-contact pigs is practiced (Kabuuka et al., 2014; Ebata et al., 2020a; Nantima et al., 2016) in order to retain the benefits from this resource, support household livelihoods and avoid financial loss. This coping mechanism was reported in this study. Participants also described how traders and butchers buy pigs at lower prices during ASF outbreaks but sell at normal prices, hence making greater profits and possibly contributing to ASF transmission while travelling to affected villages in search of cheaper pigs.

The study noted how the lack of adoption of biosecurity measures to local culture and traditions resulted in failed implementation. Specifically, this concerned the disposal of carcasses from pigs that have died from the disease as a taboo linked to misfortunes, which were frequently reported in connection with the burial of animal carcasses. In addition to being an important protein source in the food-insecure study area, the local communities considered meat a delicacy and, as such, it is unacceptable to bury or dispose of meat by burning. Consequently, a willingness to buy or barter pork from dead pigs was reported. The opportunity to make money from diseased or dead pigs serves as a disincentive to dispose of carcasses (Chenais et al., 2017b; Kabuuka et al., 2014; Dione et al., 2016a). Additionally, gathering to buy or barter pork from dead pigs allows community members to maintain social capital around an otherwise mere catastrophic event. In both these examples, pork serves as a social and economic resource that concurrently carries the negative attribute of possible ASF transmission. It was reported that carcasses disposed of by burial were exhumed for consumption. Other means of carcass disposal or virus inactivation that fitted better with local culture and traditions (such as heating or drying out of the reach of pigs) are thus needed to achieve functional biosecurity in this context. Ebata et al. (2020a) discussed how farmers are hindered from investing in biosecurity by contextual or structural factors such as poverty. Likewise, in this study, resource constraints

as well as cultural and traditional factors seemed to influence participants' opportunities to improve implementation of biosecurity. As an example of how implementation of biosecurity can be improved in resource poor settings and in agreement with local culture and traditions, a study from Timor-Leste report that participatory adaptation of biosecurity measures to the local context and applying methods inspiring community commitment motivated changes in pig management preventing ASF outbreak in study villages (Hunter, Millar, & Toribio, 2021; Barnes et al., 2020).

Finally, the results suggested that access to veterinary health care was limited and hindered ASF prevention and control for some participants. In addition, the professional relationship between local veterinarians and farmers was complicated by suspicions that veterinarians' lack of clinical hygiene might contribute to the spread of ASF. Wesonga et al. (2018) concluded that animal disease management in Uganda is ineffective, and that this is associated with inadequate and inefficient delivery of even the most basic, mandatory veterinary services.

There is no evidence supporting aerial (air-borne) transmissions of ASFV for more than a few meters inside and around pig pens (De Carvalho et al., 2012; Ann et al., 2017). According to local knowledge, however, ASFV was frequently mentioned to be transmitted aurally, and ashes of burnt pig carcasses mentioned as a risk factor for transmission. Farmers who perceive ASF as air-borne are unlikely to implement biosecurity measures that could prevent introduction of ASF, as these will not be perceived as effective if the virus "flies in the air." Likewise, an effective way of eliminating ASFV by burning carcasses at temperatures higher than 60°C (Plowright & Parker, 1967; Panasiuk et al., 2019) will not be performed if the ashes are considered infective. In this regard education actions targeting specific epidemiological subjects of concern might improve implementation of biosecurity.

The study design included purposive selection of study sites and participants. This ensures that the results are important for the local context but limits how the results can be extrapolated to other contexts. In this regard the selected farmers were considered to provide a fair representation of the study population in terms of herd size and pig management. Recent ASF outbreaks were reported from all villages, no further information regarding these outbreaks was however collected meaning that associations between individual responses regarding perceptions of ASF prevention and control and experiences of ASF outbreak could not be investigated. Equal gender representation was not achieved in this study. Although men make

most decisions concerning resource allocation for biosecurity, pigs are mostly managed by women (Ouma et al., 2015).

The underrepresentation of women could thus have led to selection bias in this regard. FGDs were held in Acholi but the analysis was made from transcripts translated to English. This could have led to loss of information depth (Clark et al., 2017). In this study this risk was reduced as the first author speaks both Acholi and English. Aspects of hidden and open power dynamics affecting how people can express their opinion and share experiences are present in all groups and will impact study results (Fischer et al., 2020a; Chenais & Fischer, 2018). Common ways to minimize this bias is to aspire that groups are as homogenous as possible regarding gender, occupation or poverty level, and not seek consensus but encourage diversity (Campbell et al., 2002). In this study efforts were made to record all opinions and consensus were not sought. Frequency of mentions were however recorded, with themes that were more present than others in the data given more weight in the final (qualitative) analysis.

In conclusion, this study demonstrated that despite mostly positive perceptions of ASF biosecurity, biosecurity measures were not being implemented due to costs of feed and housing, and the fact that family livelihood had to be prioritized over investments in disease control. Other hindrances were limitation in veterinary access and quality of services, and biosecurity measures that were not adapted to local culture and traditions. Achieving functional ASF prevention and control thus require careful adoption of biosecurity advice in participation with end users, taking local traditions, culture and the socioeconomic context into consideration. Access to pig feed and quality veterinary services are aspects that need attention in this regard. The inclusion of local veterinarians in participatory discussions on biosecurity and herd health could strengthen the client-veterinary link and improve veterinary access.

CHAPTER FIVE: INVESTIGATING ASF OUTBREAK ON A COMMERCIAL PIG FARM

This chapter presents critical analysis of ASF outbreak including sources of infections, management, and associated losses in a modern commercial pig farm. Specifically, this chapter looked at spread of ASF within the farm in terms of:

1. What are the sources of farm inputs?
2. What are the available farm biosecurity protocols?
3. How is farm structural arrangement?
4. How are pigs categorized into different groups?

5.1 Introduction

Pig production in Uganda is contributing to income security for an increasing number of people in the pig value chain (Ouma et al., 2017; UBOS, 2024). Most pigs are kept in very small herds (less than five pigs) by smallholder farmers in extensive production systems (free-range and tethering) (Dione et al., 2022). Larger herd sizes and more intensive production systems at commercial level are seen in urban areas (Muhanguzi et al., 2012). Limited market accessibility, feed availability, and disease burden including endemic occurrence of African swine fever (ASF) constrain pig production and productivity (Ouma et al., 2015; Dione et al., 2017a). In the absence of an effective and reliable ASF vaccine, implementation of biosecurity measures remains the tool available for ASF prevention and control (Penrith and Vosloo, 2009).

Large-scale commercial farmers might have higher capacity than small-scale farmers to invest in biosecurity. Having the biosecurity “hardware” such as buildings, fence, equipment, tools, and so on in place might, however, may still not be enough to prevent ASF introduction and spread if biosecurity “software” such as how the routines are implemented on a daily basis by everyone concerned is not complete (Chenais et al., 2019b). This study described an ASF outbreak in a large commercial pig farm in central Uganda, including virus introduction and internal spread. This study aimed to contribute to better understanding of the implementation of external and internal biosecurity in large scale pig farms operating in ASF-endemic settings.

5.2. Materials and methods

5.2.1 Description of study farm

The study farm, in this context called Investigated Modern Farm (IMF) was established around 2018. The IMF comprises a commercial farm located in central Uganda. During the establishment, structures that had been used to house and process chicken were transformed into a 400-sow farrow-to-finish commercial pig farm for fattening purpose, with abattoir and processing section onsite. The IMF has a synchronized breeding system with mass farrowing and weaning every two and three weeks, respectively.

5.2.2 Farm layout

The IMF has double fencing; the outer fence acts as first biosecurity line separating the farm area from the neighbouring community, and the inner fence serves as a second biosecurity line separating the pig production unit from the rest of the farm, see Figure 5.1. The IMF area located between the outer and inner fence is divided into the “red zone” and “biosecurity level 1” by an imaginary line, with the former closer to the outer fence and the latter closer to the inner fence. Farm offices, residential farmhouse, vehicle cleaning and disinfection area, security check point and an abattoir all are located near the main gate or access point of the outer fence in the red zone. Abattoir waste materials such as blood and dirty water from the work area as well as pig hair are washed down through drainage pipes. The liquid part drains into a sewage pit within the red zone and is treated with lime before draining to the soil, while any escaped solids (from the waste mixture) are sieved and buried. The abattoir has a changing room for workers entering the building.

The “Dry shower house”, bordering the red zone and biosecurity level 1, is the designated access point from the red zone to biosecurity level 1. Dry shower in this context means taking off personal clothing and putting on farm clothing. The Dry shower house has a “dirty” and a “clean” side which opens to red-zone and biosecurity level 1 respectively. After crossing through the Dry shower house, farm workers in biosecurity level 1 can proceed with their duties whereas those working in biosecurity level 2 will proceed to the respective biosecurity buildings. At the end of every workday, workers remove farm clothes at the clean side, cross to dirty side and wear their personal clothing before exiting the main gate.

The inner fence (made of woven chain link wire) demarcates biosecurity level 2, which holds the pig production unit and that is further divided into breeder and grower sections by a fence. There is an access point for movement of pigs through a fence separating breeder and grower sections. Each section has its own biosecurity houses; biosecurity house 1 and biosecurity house 2 for breeder and grower sections, respectively, as access points for people, and a container having its own biosecurity protocols for feeds entering the breeder section. The only gateway in and out of the pig production unit is through one of the biosecurity buildings. To access biosecurity level 2, both workers and visitors remove the farm clothing they put on in the dry shower house, take a shower using water and soap, cross to the clean side and put on another set of clothing for use in biosecurity level 2. At the end of workday or visit, the process is repeated but in the opposite sequence. The structural separation between biosecurity level 1

and biosecurity level 2 and the creation of biosecurity house 2 were done after the 2021 ASF outbreak (Figure 5.1).

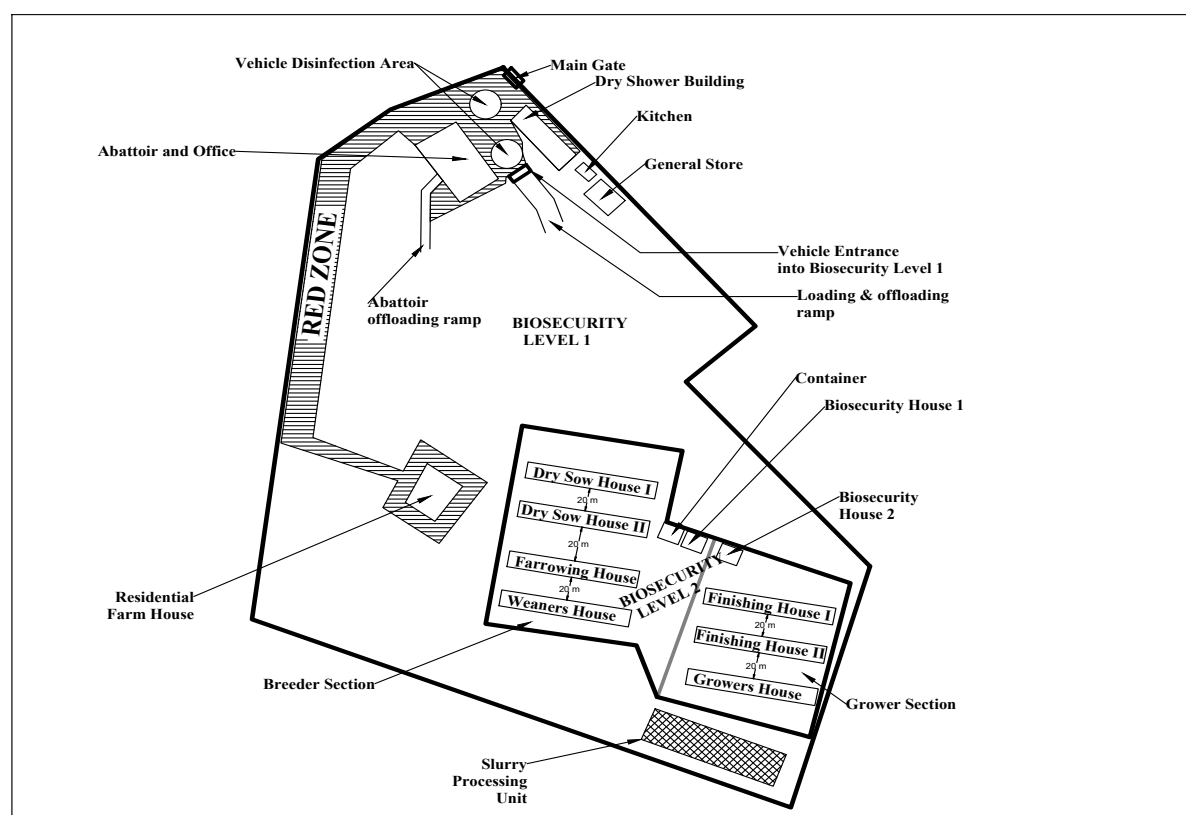


Figure 5.1: Schematic drawing of the pig house structures in the IMF

5.2.2 Pig housing structures

Structural arrangement of different pig houses is presented in Figure 5.2. The pig production unit has one breeder and one grower section composed of four and three pig houses, respectively (Figure 5.2). The houses are, 1): Dry Sow House I (DSH-I) partitioned into 30 pens, 2): Dry Sow House II (DSH-II) partitioned into Boar Station and Artificial Insemination Station (AI- Centre). DSH-II is further subdivided into 24 pens and the Boar Station into eight pens, 3): The Farrowing House is divided into three units composed of Farrowing House A and Farrowing House B, each with 38 farrowing pens, and an AI-Station having 72 pens, 4): The Weaner House is divided into four units composed of: Weaner House I, II and III, and a Replacement Gilt Rearing House (RGRH) (partitioned into 10 pens), 5): The Grower House partitioned into 12 pens, 6): The Finishing House II partitioned into 20 pens and 7): The finishing House I partitioned into 20 pens. All seven pig houses have a feed silo. The distance between any adjacent buildings is 20 meters.

The materials used in the pig structures for partitioning include: a combination of short solid wall and metal bar rails for DSH-I, DSH-II and the RGRH, Polyvinyl Chloride (PVC) plastic panels separating crates used in rooms in the farrowing houses and for the pens in the weaner's houses. Weaners houses have PVC panels reinforced with metallic bar rails at the top. Short solid wall and double-sided feeder, and short solid walls are used as partition materials in growers and finishers houses, respectively. Metallic bar rails are used to partition AI stalls in the AI Station.

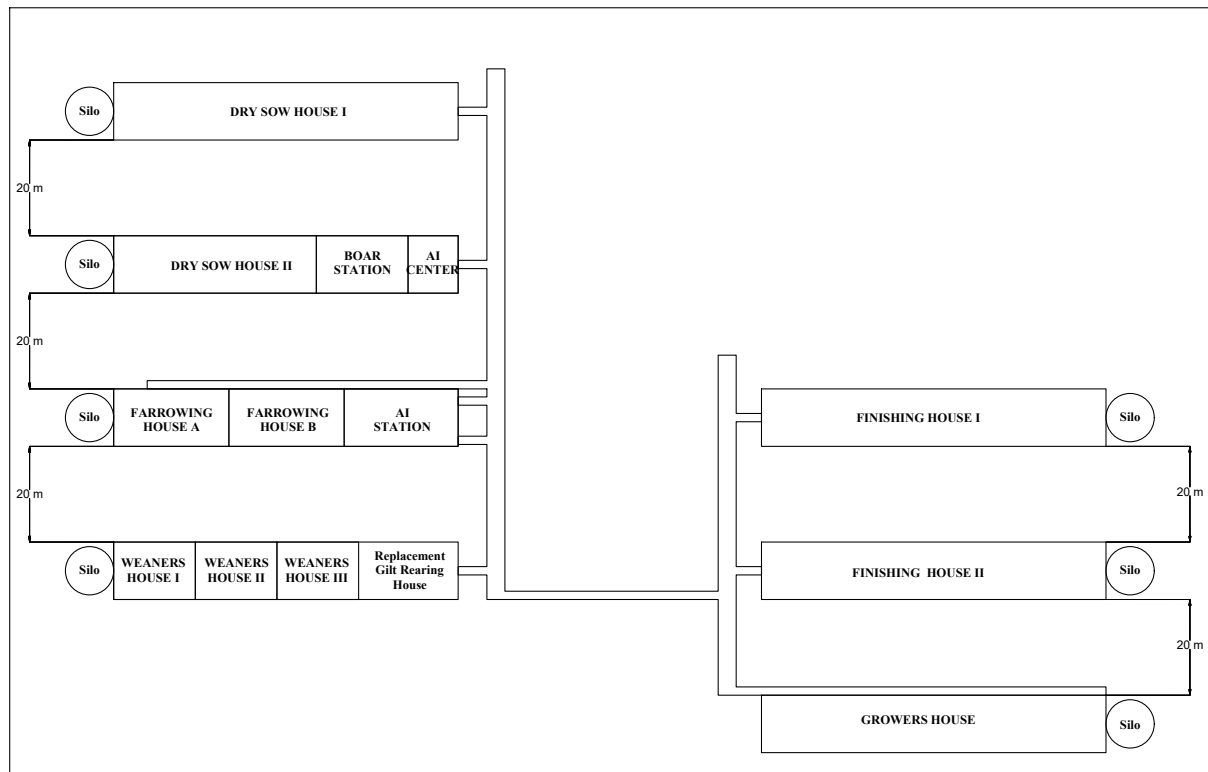


Figure 5.3: Schematic drawing of the pig house structures in the IMF

5.3. Case definition

An individual pig was considered as a case of ASF after a positive PCR test, or post-mortem findings indicative of ASF infection such as petechial hemorrhage of the kidneys and/or enlarged spleen. An individual pig was considered a suspected case of ASF if it presented with high fever (over 40°C) or skin hyperemia. An in-contact individual case was a pig that shared the same pen with at least one confirmed or suspected case. A pig house was considered as infected if it housed at least one confirmed or suspected case.

5.4 Data collection

The study concerned two ASF outbreaks (May to June 2021, and April to July 2022) and, comprised of interviews with farm manager and vet officer to gather information regarding farm biosecurity and feed handling, collection of biological and feed samples, as well as extraction and analysis of farm records. During the investigation, the farm director and veterinarian were informally interviewed with notes taken simultaneously to capture information on: ASF outbreak history and spread within the farm, pig inventory, morbidity and mortality records, biosecurity routines, feed types and their sources, farm structures arrangement, pig production cycle, and pig movement within the units before and during outbreak periods. In addition, photographs were taken and observations made.

5.4.1 Sample collection

During the 2021 outbreak, whole blood samples were collected in EDTA-coated sterile vacutainer tubes from the jugular vein of suspected ASF cases and in-contact pigs. Tissue samples (spleen and lymph nodes) were collected from dead pigs in 2021 and 2022, and from frozen carcasses of slaughtered pigs in 2022, all tissue samples were put in sterile cryovials. In 2021, blood and organ sampling from all age groups was done to monitor ASF incidence within each section. In 2022 mainly tissue samples from adult pigs were taken, in order to avoid dispatching ASFV infective carcasses from the farm. Feed samples were collected into zip bags from trailers while feed was being offloaded into silos and from the mills at the feed manufacturing company. Whole blood, tissue, and feed samples were transported to the College of Natural Sciences (CoNAS) in Makerere University for laboratory analysis. Laboratory reports were provided to the farm manager the following day after the samples were received in CoNAS.

5.4.2. Laboratory investigation

5.4.2.1. Genomic DNA extraction

Genomic DNA was extracted from blood, tissue and feed samples. ASFV DNA was extracted from 100 µl of whole blood or 10 mg of tissue and a final eluate of 200 µls was obtained using the DNAeasy Blood and Tissue kit (Qiagen, Germany) following manufacturer's instructions. The feed samples (5 mg) were first mixed with 5mls of Phosphate-Buffered Saline (PBS) solution and then an aliquot (200 µl) of the homogenized solution was used for extraction of

DNA material. Presence of extracted DNA was confirmed by running the samples on a 2% agarose gel stained with ethidium bromide.

5.4.2.2 ASFV detection

Detection of ASFV genome in pig (blood and tissue) and feed samples was done using two PCR assays (RT-PCR and conventional PCR) depending on the availability of a particular assay in the laboratory at the time the samples were delivered.

5.4.2.2.1 Real-Time polymerase chain reaction (RT-PCR)

A commercially available RT-PCR kit (Tetracore Inc., Rockville, MD, USA) and Smart Cycler DX 3.0 (Cepheid, Sunnyvale, CA, USA) is used for the detection of ASFV DNA in the feed additives (n = 8), ingredients (n = 20) and formulated feed samples (n = 32), and tissue samples (n = 6) following the manufacturer's protocol. Positive and negative controls were supplied with the RT-PCR kit.

5.4.2.2.2 Conventional PCR

PCR was conducted following protocol described by Ogweng et al. (2024). Amplification of the ASFV segments was carried out using the primer pair PPA1-5'-AGTTATGGGAAACCCGACCC-3' and PPA2-5'-CCCTGAATCGGAGCATCCT-3' amplifying a 278 bp region corresponding to the central portion of the p72 gene. With PCR, the ASFV genome can be detected from tissues, serum and blood at a very early stage in the infection, not possible using ELISA. It is therefore often the most suitable technique. PCR amplification was done in a 25 mls reaction volume: 2 mls of the template DNA was added to 23 mls of a commercially available One *Taq* Quick-Load 2X master mix with standard buffer (New England Bio Labs Inc, UK). The cycling conditions were: initial denaturation 95°C for 10 minutes for 1 cycle, denaturation at 95°C for 15 seconds, annealing temperature was at 55°C for 30 seconds, extension temperature was at 72°C for 30 seconds, final extension temperature at 72°C for 7 minutes and holding temperature at 4°C. The denaturation, annealing and extension steps were repeated for 35 cycles. The PCR results were confirmed positive or negative by running the samples on a 2% agarose gel with a positive control sample and a molecular marker (DNA ladder). In-house controls (positive and negative) were used. The

positive control was previously purified from positive cases with sequencing data available to confirm ASFV strain.

5.5 Data analysis

Status quo of activities in the production unit were summarized into narratives based on specific routines which occurred before ASF outbreaks. Statistical analyses were conducted following laboratory confirmation of ASF DNA presence in the biological sample investigation. With the application sigma-plot (version 12.5) software for statistical analysis, epi-curves and bar graphs were constructed using farm mortality records to describe the trend of ASF cases amongst different pig categories, and across pig houses. These results, especially for pig mortality rates (number of dead pigs per week) are presented in Figures 3.3, 3.5a, 3.6, and 3.8a. Sketch diagrams (Figure 5.4 and 5.7) illustrated pig movement between houses and (Figures 5.5b and 5.8b) the spread of infection between houses. Odds ratios (OR) of being near to potential risk access areas for ASFV entry in biosecurity level 2 such as Loading Ramp-I, Loading Ramp-II, Container, Biosecurity House-I, and Biosecurity-II were calculated to determine the association between the location and number of pig houses which had early infection (sudden increase in pig deaths)". "Being near to" refers to a distance of less than 20 meters between early infected houses and the risk areas of interest. The software 'epiR' package was used to estimate OR. The Fisher Exact Chi-squared Test was used as the statistical test on the calculation of OR, see appendices 5.1 and 5.2. Strict biosecurity measures included in "Disease Outbreak Contingency Plan" were summarized.

5.6 Results

5.6.1: Pre-outbreak routines

5.6.1.1. Pig movement flow within biosecurity level 2

Pig transfers from one house to the next were done by walking them along paved pathways. Pregnant sows were moved from DSH-I and/or DSH-II to the Farrowing house 14 days before farrowing. After farrowing, sows nursed their piglets for three weeks before weaning. Weaned sows and piglets move from the farrowing house to the AI section and weaner house, respectively. Weaners were transferred to the grower house at the age of 8 weeks and those selected as replacement gilts for breeding were transferred to RGRH. Growers spent six weeks in the growers' house before they are moved to the finishing house, where they were raised until slaughter at 22 weeks of age. Replacement gilts were reared in the RGRH until the age of

24 weeks when they were transferred to DSH-I for teaser-boar exposure and further management. After the second heat, gilts were transferred to the AI section where they were inseminated (with boar semen collected and processed on site in the AI center) during the third heat at the age of 32 weeks together with weaned sows. After insemination, sows were moved into group pens in either of DSH-I or DSH-II. Sows that recycle were either re-inseminated or culled.

5.6.1.2 Pig movement flow within biosecurity level 1

All pigs were moved using a trailer which operates strictly within biosecurity level 1. Pigs ready for slaughter or sale were driven from the breeder section to a gate created in the inner fence near DSH-I, or from the grower section to a gate in the inner fence near Finishing House I. Slaughter pigs are loaded onto a trailer usually parked close to those gates (in this context called pig production unit gates) on the biosecurity level 1 side. The slaughter pigs were transported by this trailer through the biosecurity level 1 to the abattoir where the pigs were offloaded using the abattoir offloading ramp. Sold pigs are loaded onto a trailer and driven from the pig production unit gates to the loading and offloading ramp at “vehicle entrance into biosecurity 1”.

After the 2021 outbreak, pigs were loaded onto a trailer using the loading and offloading ramp at “vehicle entrance into biosecurity 1”, driven through biosecurity level 1, and offloaded at the pig production unit gates. Pigs offloaded at the pig production unit gates were moved by foot on the paved pathways to empty units in the breeder section where they were raised under quarantine conditions for five weeks.

5.6.1.3 Feed handling

This section describes the processes of transporting feeds to, and handling of delivered feeds within IMF. Some feeds are purchased from feed manufacturing companies in Kampala and some feed ingredients are sourced from different parts of Uganda and mixed at the farm. Feeds and feed ingredients are transported to IMF using the farm’s own tractor-driven bulk trailers and refrigerated trucks. Tarpaulins are used to cover unbagged feeds loaded on to bulk trailers. Bulk trailers carry both un-bagged (bulked) and bagged feeds, refrigerated trucks carry only bagged feeds. Within IMF, un-bagged feeds are delivered to an auger filling machine (used to transfer/pump feeds into the silos) located in biosecurity level 1 near breeder section and

sucked across the inner fence into silos located in biosecurity level 2. Each of the seven pig houses has its own silo and auger filling machine system. At feeding, feed from the silos is pumped through delivery pipes into feed troughs in the pig pens. Bagged feeds are delivered to the pig production units through a container beside biosecurity house 1. This container is divided by an imaginary line into dirty and clean areas and has an access point through the inner fence to biosecurity level 2. Bagged feeds are placed in the dirty area, the surface disinfected and transferred to the clean area of the container. Feeds from clean area are loaded onto wheelbarrows and delivered to feed troughs in the pig pens.

Feeds delivered in bags are usually specific for a group of pigs; creep feeds for piglets, starter feeds for weaners, replacement gilt feed for replacement gilts and flush feeds for sows. Replacement gilts and sows in the AI section are fed manually while piglets and weaners are fed through delivery pipes from the silos.

5.6.1.4 Food distributions to workers

Food cooked in the kitchen located in biosecurity level 1 were served to all IMF workers. Workers in biosecurity level 1 converge at the kitchen to have meals. Cooked foods were taken to the abattoir for the abattoir workers. Cooked foods were also taken to biosecurity houses 1 and 2 where biosecurity level 2 workers in breeder and grower sections, respectively. The lunch area inside the biosecurity houses could be accessed without showering.

5.6.2 The 2021 ASF outbreak

5.6.2.1 Temporal-spatial distribution

Epi-curves of weekly deaths in groups of sows, boars, suckling piglets, weaners, gilts, growers and finishers before and during 2021 confirmed ASF outbreak (excluding euthanized 740 critically sick pigs) are shown in Figure 5.3. The first ASF cases were suspected when a sow died on 12th May 2021 (in week 18) and its postmortem (PM) findings were associated with septicemia. This followed death of two sows which occurred in week 17 and no PM were done. No death of sows was observed for over four weeks prior to week 17. The samples collected from the dead sows on 20th May 2021 (week 19) tested ASFV genome positive by PCR.

In order to contain the confirmed ASF outbreak in sows and prevent its spread to other pig categories, in week 19, IMF director approved from “Disease Outbreak Contingency Plan” sets of biosecurity measures which include; no movement of equipment in between houses,

maintain routine pig flow movement within the system, remove infected animals and disinfect abandoned houses, and disposal of dead pigs through composting or deep burial or incineration. Other biosecurity measures enhanced were the subdivision of houses based on specific control measures, workers assigned to clean (unaffected) and dirty (affected) houses/pens have separate color overalls and gumboots, dirty workers to avoid contact with clean workers, use shower facilities at designated points (e.g. biosecurity houses I and II), and unauthorized persons were not allowed onto the unit. Biosecurity measures were instituted timely, but deaths of sows continued.

Epi-curve show that death of sows increased sharply from four (in week 19) to 147 (in week 20). In other pig categories, death of boars (n=2) and gilts (n=5) started in week 20 and the number increased slightly in week 21 (n=12) and in week 22 (n=18), respectively. There were ongoing weekly deaths of growers, finishers, and weaners for over five weeks before ASFV was confirmed amongst sows in week 19. However, deaths number increased studently in growers (from n=10 in week 21 to n=111 in week 22), followed by finishers (from n=5 in week 22 to n=181 in week 23), and in weaners (n=10 in week 23 to n=94 in week 24). By the end of week 23, ASF had infected all pig categories except for suckling piglets, which were dying (avg=24 per week) of other causes (IMF Veterinarian mentioned pneumonia and weakness) for over six weeks before ASF was confirmed in sows in week 19. Suckling piglets maintained the same death rate in weeks 19 and 20, paused in week 21, and ended with a few deaths (n=2) in week 22.

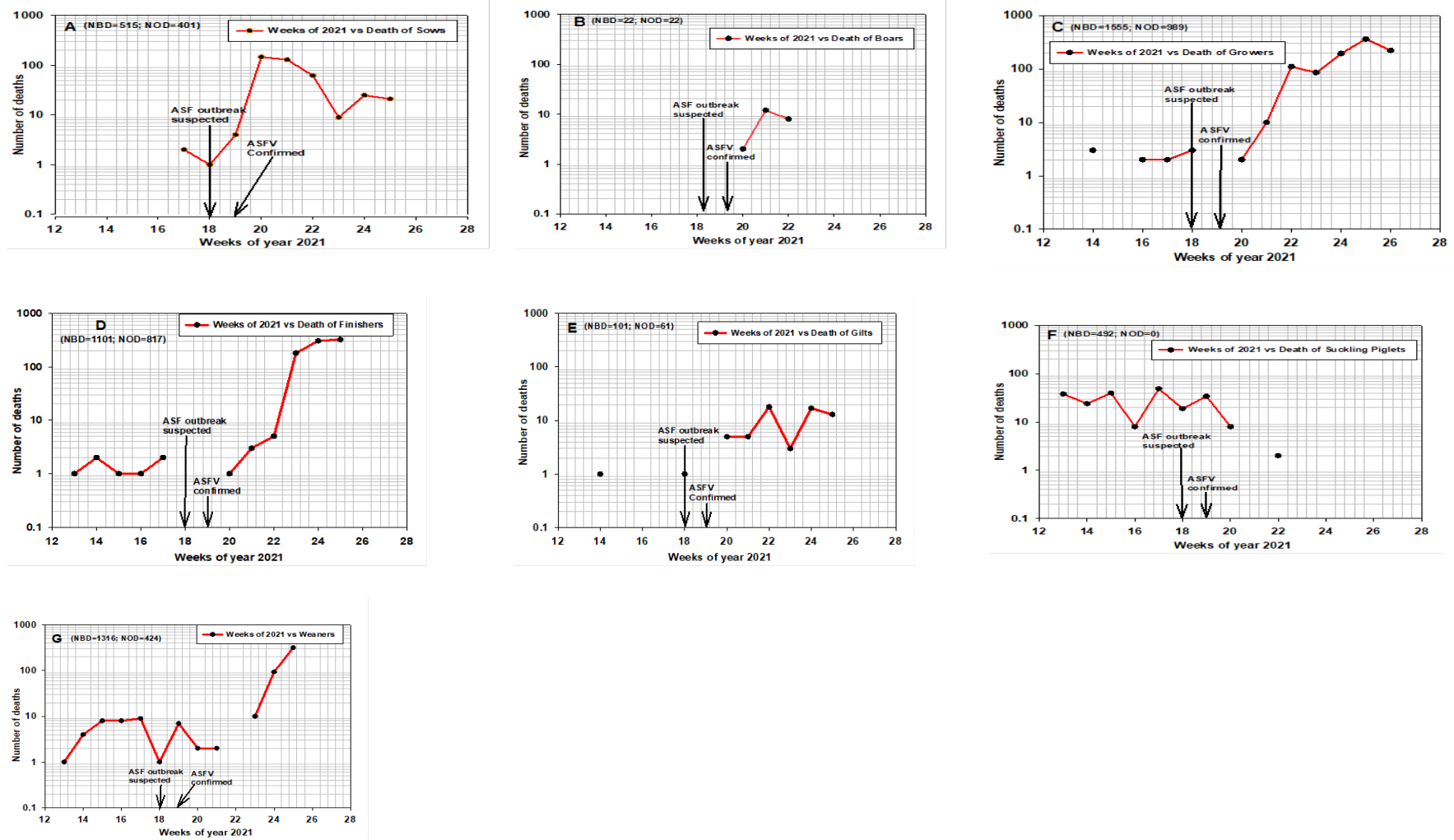


Figure 5.2: Epi-curves show mortalities in different pig categories before and during 2021 ASF outbreak

- Pig categories are denoted as letters which include: A=Sows; B=Boars; C=Growers; D=Finishers; E=Gilts; F=Suckling; G=Weaners.
- Number of live and dead are denoted as: NBD=Number of live pigs available just before suspected ASF outbreak; NOD=Number of pigs which died during ASF outbreak.
- Weeks of year 2021 denoted as 12 through 28 represent seven dates such as: 12=28th March – 3rd April; 13=4th – 10th April; 14=11th – 17th April; 15=18th – 24th April; 16=25th April – 1st May; 17=2nd – 8th May; 18=9th – 15th May; 19=16th – 22nd May; 20=23rd – 29th May; 21=30th May – 5th June; 22=6th – 12th June; 23=13th – 19th June; 24=20th – 26th June; 25=27th June – 3rd July; 26=4th – 10th July; 27=11th – 17th July; 28=18th – 24th July).

5.6.2.2 Pig movement across different houses

Temporal and spatial pig movements during 2021 ASF are presented in Figure 5.4. The direction of pig movement within and across houses is represented by arrows numbered from m1 to m8 and the corresponding dates of movement are shown in legend. The first arrow (m1) indicates movement of 41 sows on 20th May 2021 from Farrowing House A to Farrowing House B, and the same day four sows showing ASF signs were moved (m2) from AI station to DSH-I. On 21st May 2021, three sick sows were moved (m3) from DSH-II to DSH-I. DSH-I continued to receive more pigs such as one inseminated gilt moved (m4) from AI-Station on 23rd May 2021 and some growers were moved (m5) from Growers House on 25th May 2021. More pig movements (m6, m7 and m8) occurred as indicated in the figure.

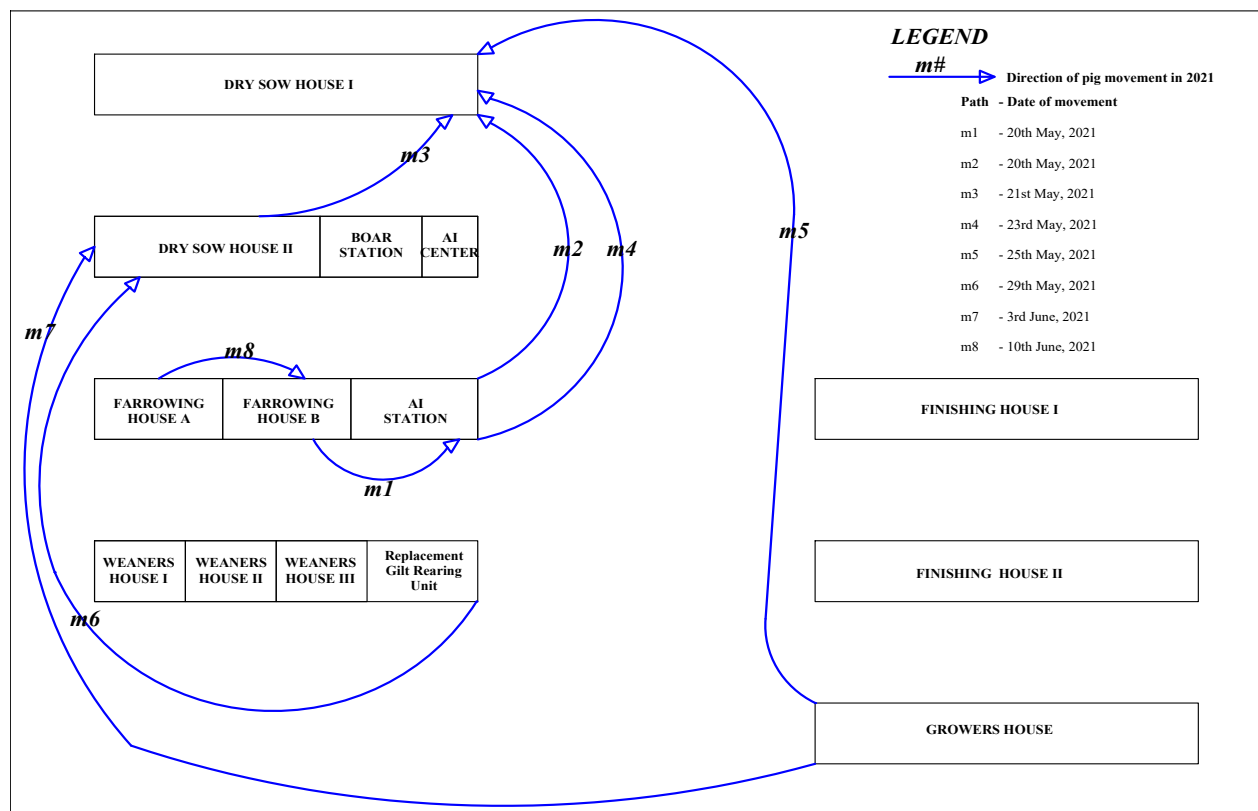


Figure 5.3: Schematic drawing of pig movements across houses in 2021 ASF outbreak

5.6.2.3 Pig mortality distributions across houses

Bar-graphs showing weekly death of pigs in houses are presented in Figure 5.5. The first suspected pig (an index case) was observed on 12th May 2021 (week 18) in DSH (in pen-13 of DSH-I). More deaths (n=4) occurred in pens DSH in week 19. After ASFV was confirmed in

DSH in week 19 pig deaths occurred in other houses. Two and five deaths reported in Boar Station (BS) and Replacement Gilt Rearing House (RGRH), respectively in week 20, followed by Growers House in week 21, Finishers House in week 22, and Weaners House in week 23. Deaths in houses lasted longest (nine weeks) from week 17 to week 25 in DSH, followed by six weeks, from weeks 20 to 25 in RGRH and from weeks 21 to 26 in Growers House, respectively, and finally for three weeks only in both Boar Station and Weaners House from week 20 to week 22 and from week 23 to week 25, respectively. Massive deaths of over 50 pigs maintained for at least three different weeks were observed in Growers House in week 22 (n=111), 23 (n=86), 24 (n=195), 25 (n=364), and 26 (n=223); followed by Finishers House in weeks; 23 (n=181), 24 (n=307) and 25 (n=324); in DSH in weeks; 20 (n=147), 21 (n=130) and 22 (n=65) and finally in Weaners House in weeks 24 (n=94) and 25 (n=320). In RGRH and Boar Station which hosted fewer pigs had relatively low deaths per week.

The trends of pig deaths across houses, over time, formed a basis for drawing illustration diagram portraying access areas for ASFV entry and ASF spread in houses as shown in Figure 5.6. Death cases remained in an index house (DSH-I) from week 17 through week 19. ASF spread out of DSH-I. In week 20 high deaths were reported in other houses such as DSH-II, Boar Station, and RGRH. ASF spread and caused pig deaths in Growers House in week 21, Finishers House in week 22 and Weaners House in week 23. Five structures (Ramp-I, Ramp-II, Container, Biosecurity House-I and Biosecurity House-II) in the sketch diagram, are potential access points for ASFV entry into production unit based on their relative to pig houses which had early pig deaths.

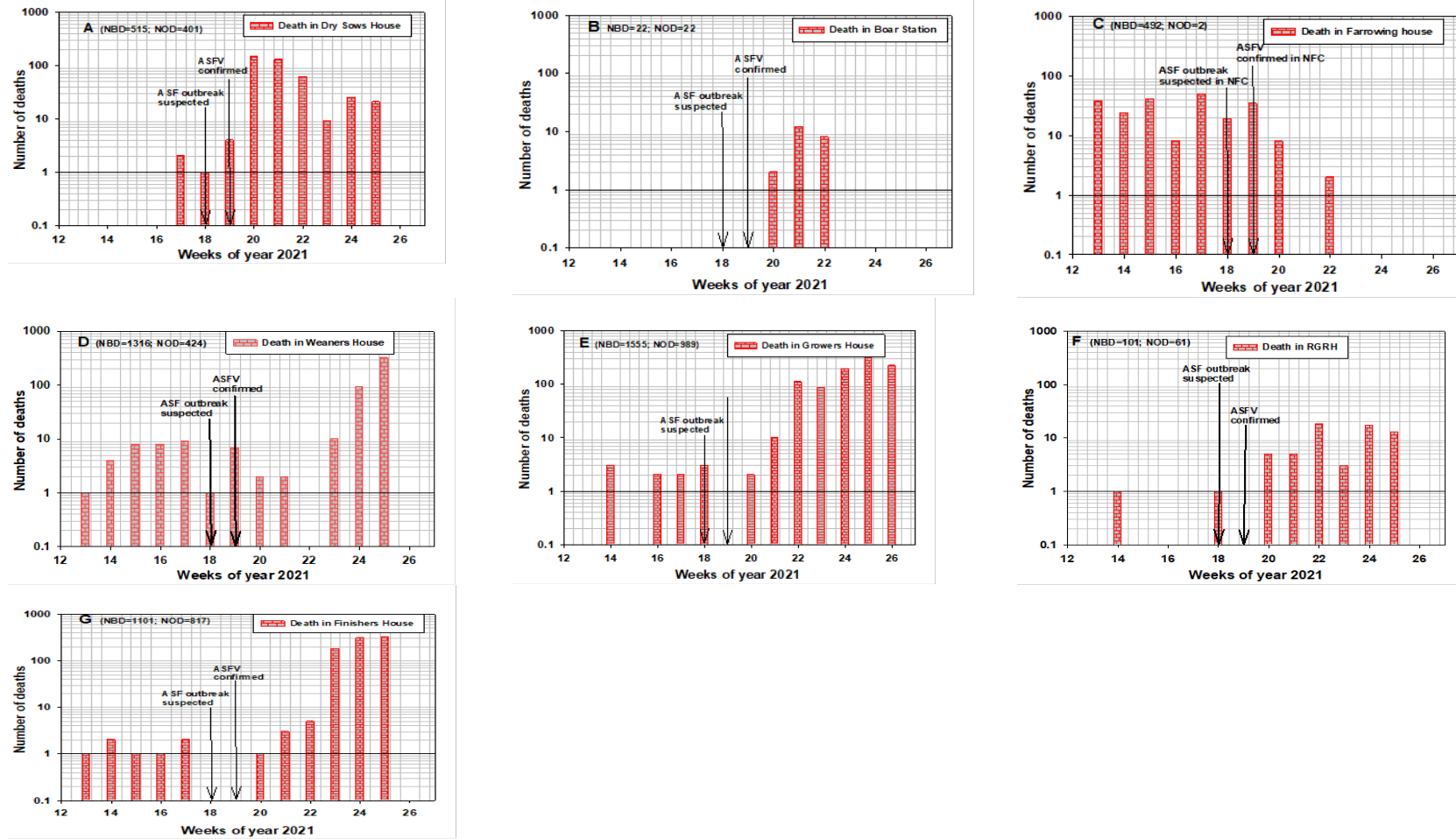


Figure 5.4: Bar graphs of pig mortalities in different houses during 2021 ASF outbreak

- Pig categories are denoted as letters which include: A=Sows; B=Boars; C=Growers; D=Finishers; E=Gilts; F=Sucklings; G=Weaners.
- Number of live and dead are denoted as: NBD=Number of live pigs available just before suspected ASF outbreak; NOD=Number of pigs which died during ASF outbreak.
- Weeks of year 2021 denoted as 12 through 28 represent seven dates such as: 16=25th April – 1st May; 17=2nd – 8th May; 18=9th – 15th May; 19=16th – 22nd May; 20=23rd – 29th May; 21=30th May – 5th June; 22=6th – 12th June; 23=13th – 19th June; 24=20th – 26th June; 25=27th June – 3rd July; 26=4th – 10th July).

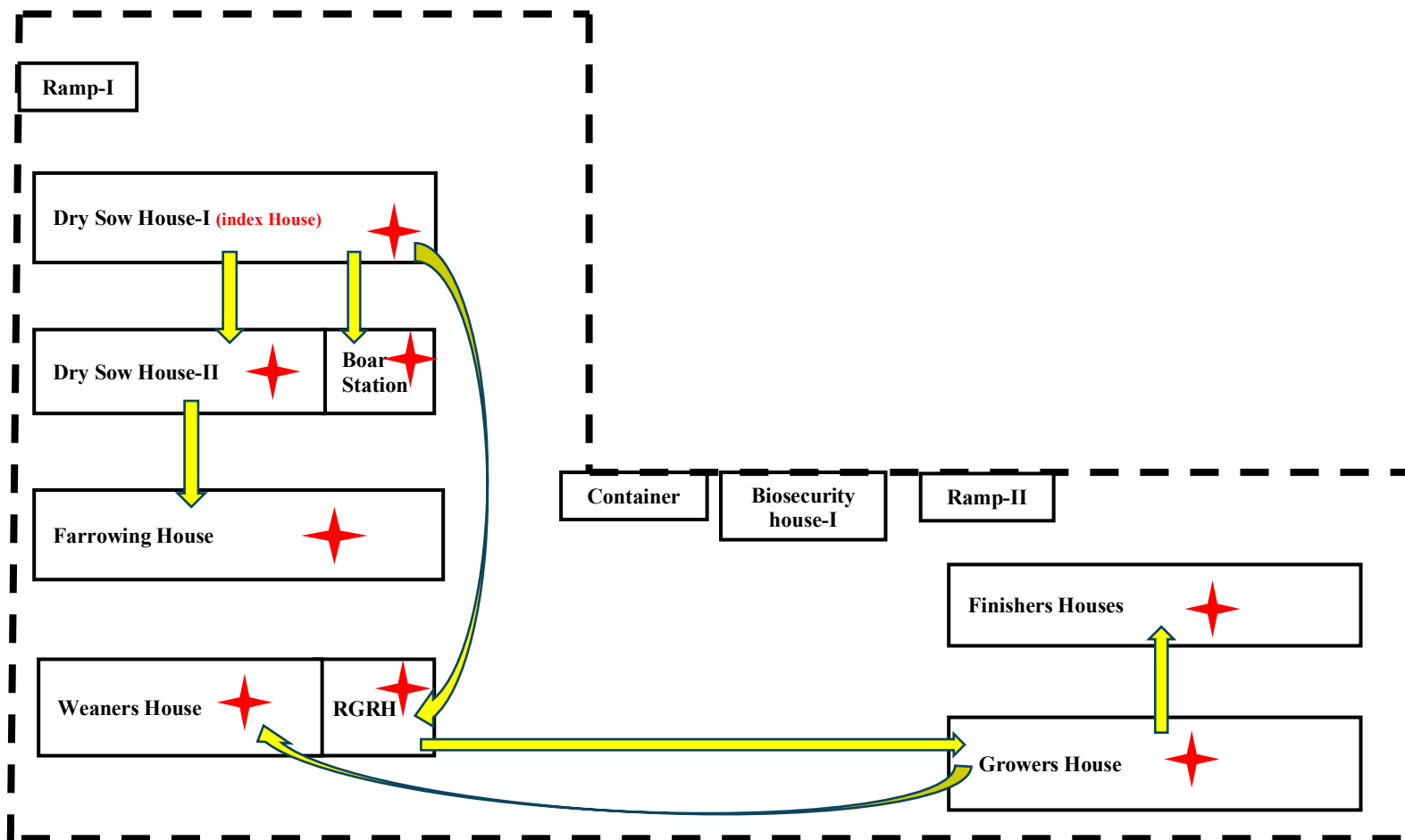


Figure 5.5: Schematic drawing death of pigs (denoted red star) in pig houses and direction of ASFV spread (denoted yellow arrow) across pig houses during 2021 ASF outbreak
Dashed line is a running inner fence made of chain link wire.

5.6.2.4 Introduction of ASFV to the IMF in 2021 outbreak

In Figure 5.6 above, Ramp-I is a structure in “Breeding Section” attached to “pig production unit gate” near DSH-I (refer to section 3.1.2) was used for loading slaughter sows onto trailer destined for abattoir and similarly for loading onto a trailer the weaners sold to out-growers farmers. Ramp-II attached to pig production unit gate near Finishers House-II (refer to section 3.1.2) was used for loading finishers for transfer to abattoir. Container (see section 3.1.3) is an entry point for bagged feeds into production unit, and Biosecurity House I (see section 2.3.0) are workers’ entry points into production unit. In Biosecurity Houses I, workers are expected to shower, change clothes and boots, and disinfect before entering production unit. Bagged feeds are also expected to be disinfected in the container prior to delivery into production units. Cleaning and disinfection facilities were not provided at the Ramp-I and II for production unit workers involved in loading. Pig houses in production unit were linked to the mentioned five potential risk structures which connect pig houses to the outside. Early infection, in this context, sudden increase in deaths from week 17 through week 20 (see Figures 5.5 and 5.6) occurred in DSH1, Boar Station and RGRH, with DSH-I being an index pig house. Ramp-I, Container, and Biosecurity House-I were being near to one or two of the three “early infected houses”. The odds ratio of ‘being early infected’ in relation to the different locations are shown in Table 5.1. There were significant association ($P < 0.001$) with Ramp-I and Container

Table 5.1: *The odds ratio (OR) for three pig houses in different locations being “early infected” on IMF investigated in 2021*

Potential risk areas	OR	95% CI		P value
		Lower	Upper	
Being near to Ramp-I	6.20	2.96	13.01	< 0.001
Being near to Container	0.16	0.08	0.34	< 0.001
Being near to Biosecurity House-I	0.28	0.07	1.22	< 0.072

According to IMF – director’s thoughts on sources of ASFV introduction to the farm, production unit employees were unlikely due to double layers (biosecurity level-I and II), automated shower in Biosecurity House, and the training they acquired. Another unlikely source mentioned was equipment because of routine disinfection before use. However, the possible two sources revealed include; 1) sales of weaners to out growers if trucks were not properly disinfected at the gate before entering premises, and 2) feed contamination was most probable based on the facts that some gestating sows fed on feed bagged at mill, started

showing symptoms after a week and contamination most likely occurred at feed mill due to high cases of ASF then in the neighborhood. No feed samples were analyzed in laboratory for ASFV presence in 2021 outbreak.

5.6.3 The 2022 outbreak

5.6.3.1 Temporospatial distribution of ASF in production unit

In 2022 ASF outbreak, IMF records of 23rd April through 7th May show that 253 apparently healthy pigs, especially sows, gilts and finishers were culled through slaughtering, and the PCR analysis of their carcass samples revealed that 29% (73/253) were positive for ASFV. The tested negative (71%) carcasses were sold. Epi-curves showing weekly pig mortalities before and during 2022 ASF outbreak (excluding the 73 pigs tested ASFV positive which would have died if they were not slaughtered) are presented in Figure 5.7. On 17th April 2022 (week 15), an index case boar died, and a laboratory analysis of its organ samples was tested positive for ASFV the same day by PCR. Second boar died in the same week 15. Veterinary officer of IMF revealed that cases of pre-partum sow deaths were common for several weeks preceding 2022 ASF outbreak, especially sows of first parity which were dying of gastric ulcers and ileitis. The ongoing deaths of sows which occurred on average, two per week, for over six weeks before ASF was confirmed, slightly increased to four towards end of week 15 (on 21st April 2022). Number of dead boars and sows increased to 6 and 32, respectively in week 16. Deaths amongst growers and weaners occurred weekly for over six weeks before ASF confirmation but increased sharply (from n=4 in week 20 to n=23 in week 21 and from n=9 in week 24 to n=39 in week 25), respectively. Suckling piglets were dying (average=27 weekly) from week 8 through week 15, but the deaths number dropped to below average from week 16. Isolated death which occurred in finishers and gilts categories are presented in their respective epi-curves.

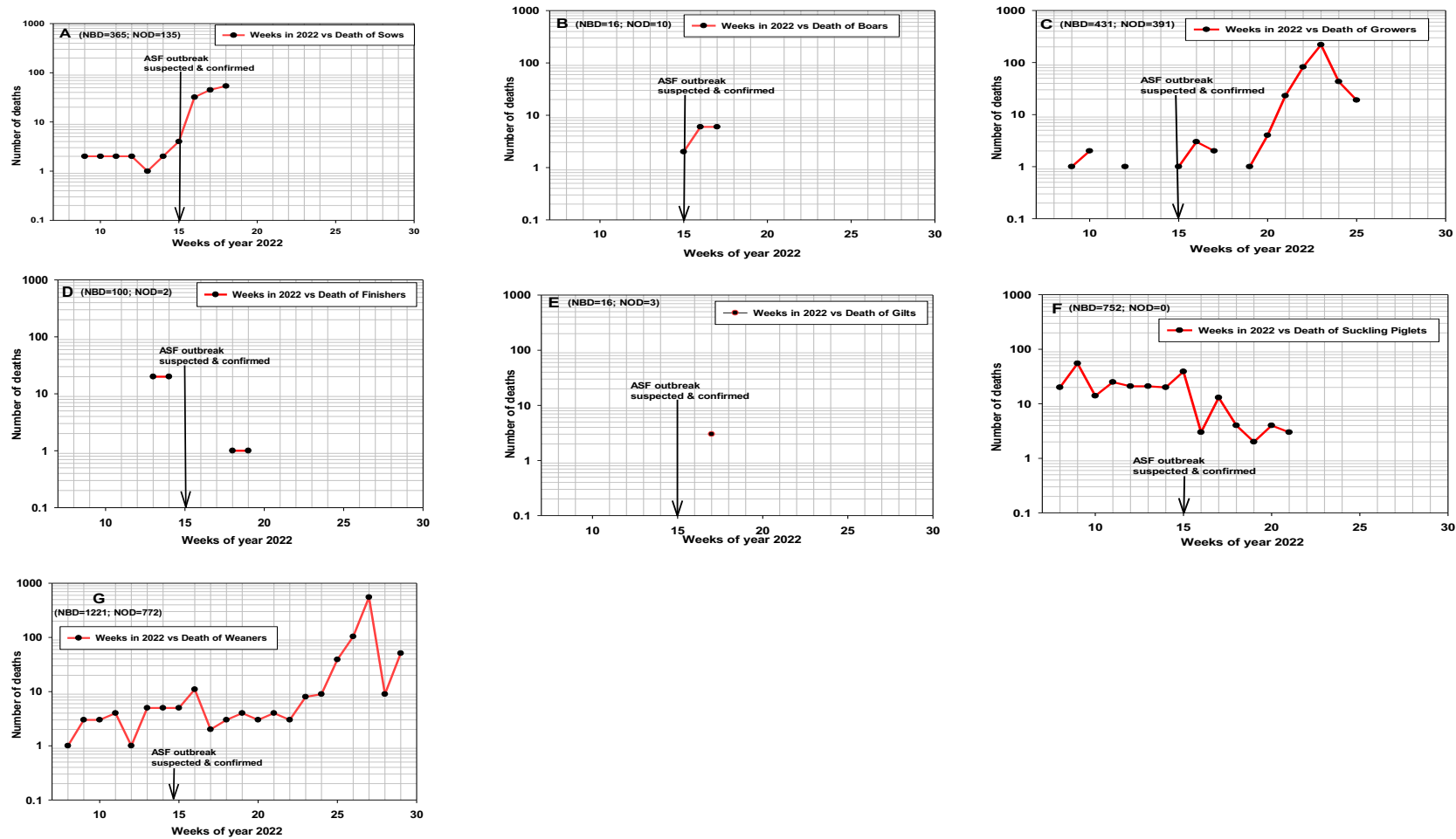


Figure 5.6: Epi-curves show mortalities in different pig categories before and during 2022 ASF outbreak

- Pig categories are denoted as letters which include: A=Sows; B=Boars; C=Growers; D=Finishers; E=Gilts; F=Sucklings; G=Weaners.
- Number of live and dead are denoted as: NBD=Number of live pigs available just before suspected ASF outbreak; NOD=Number of pigs which died during ASF outbreak.
- Weeks of year 2022 denoted as 10 through 30 represent seven dates such as: 10=13th – 19th March; 11=20th – 26th March; 12=27th March – 2nd April; 13=3rd – 9th April; 14=10th – 16th April; 15=17th – 23rd April; 16=24th April – 31st April; 17=1st – 7th May; 18=8th – 14th May; 19=15th – 21st May; 20=22nd – 28th May; 21=29th May – 4th June; 22=5th – 11th June; 23=12th – 18th June; 24=19th – 25th June; 25=26th June – 2nd July; 26=3rd – 9th July; 27=10th – 16th July; 28=17th – 23rd July; 29=24th – 30th July; 30=1st – 7th Aug.

5.6.3.2 Pig movement across houses in 2022 ASF outbreak

Temporal and spatial spread of apparent ASFV during the 2022 ASF outbreak is presented in Figure 5.8. On 14th April 2022, two batches of sows and gilts were moved from AI station to DSH-II as indicated by arrow m1 and to DSH-I indicated by m2. Third pig movement (m3) was on 26th April 2022 from DSH-II to DSH-I. Other pig movements occurred including the transfer (m5) of growers within Growers House from pen-4 to pen-3 on 19th May 2022. The last movement (m6) involved a sow from Farrowing House to AI station on 28th June 2022.

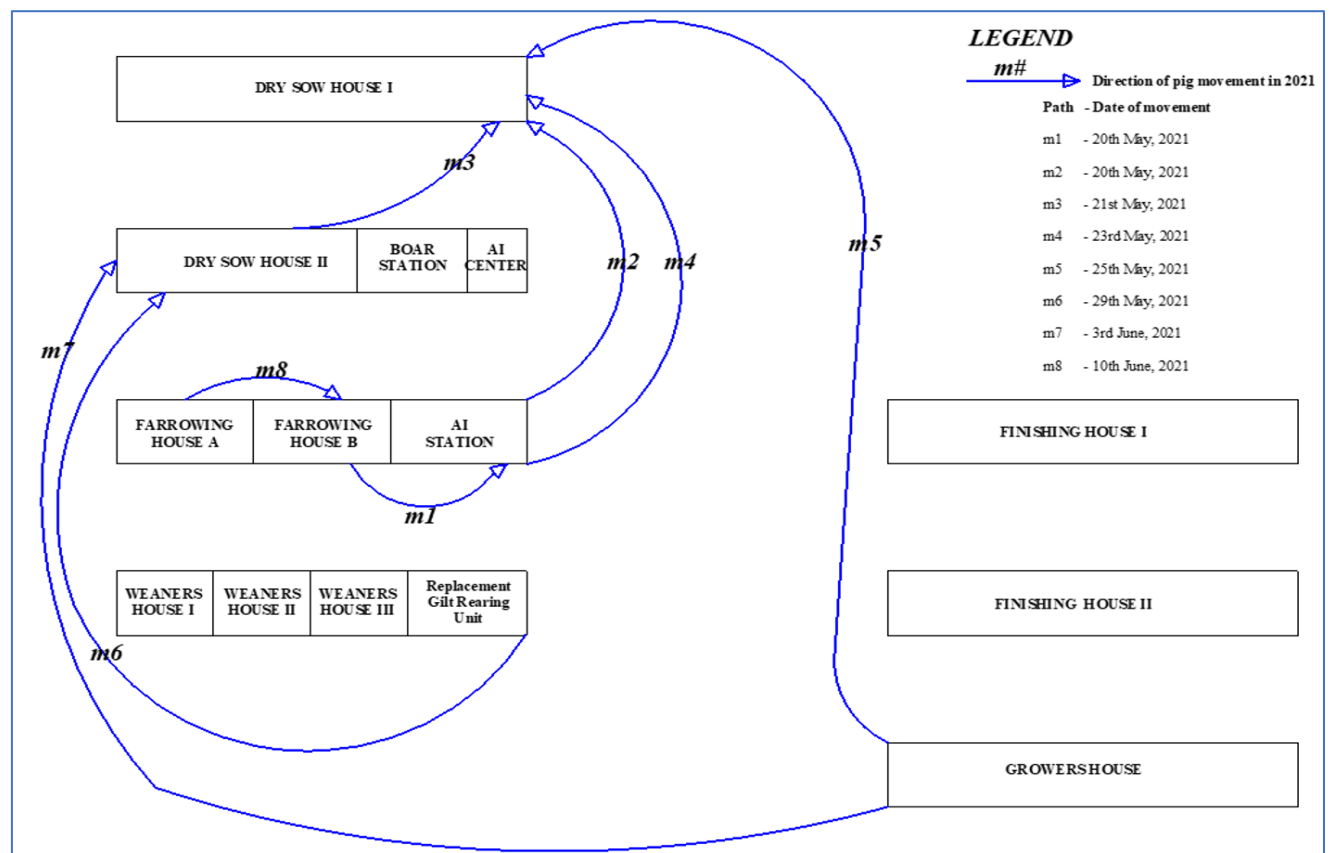


Figure 5.7: Schematic drawing of pig movements across houses in 2022 ASF outbreak

5.6.3.3 Pig mortality distributions across houses in 2022 ASF outbreak

Bar-graphs showing weekly death of pigs in houses during 2022 are presented in Figure 5.9. On 17th April 2022 (early week 15), an index pig which died in Boar Station tested positive for ASFV that same day. Bar-graph show two deaths occurred in Boar Station in week 15. After

the laboratory confirmation of ASFV in Boar Station in early week 15, four deaths occurred in DSHs towards end of week 15 (on 21st April 2022). Death number increased in both Boar Station and DSH to six (in week 16) and to 32 (in week 16), respectively. There were isolated deaths which started and ended suddenly in RGRH (n=1 in week 17 and n=1 week 18) and in Finishers House (n=3). Pigs were dying in Growers House (average=3 per week) and in Weaners House (average=1 per week) for over six weeks prior to ASF confirmation in week 15, it continued until when there was sudden increase in death number above average in Growers House to 23 pigs in week 21 and in Weaners House to 39 pigs in week 25. Bar-graph shows deaths in Farrowing House which occurred weekly (average=28) from week 8 through week 15, then a drastic decrease in deaths (average=5 pigs per week) from week 16 to week 21.

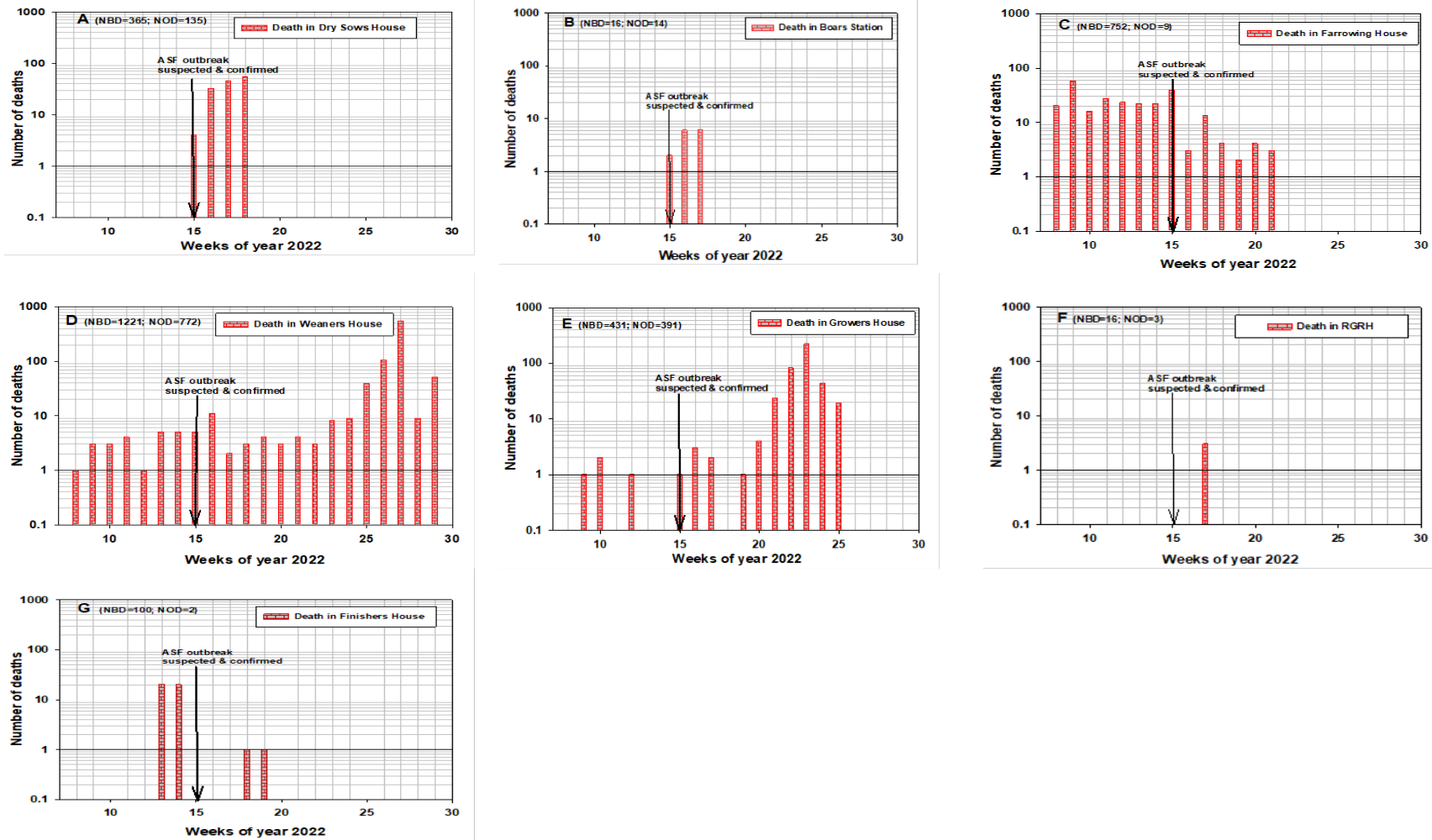


Figure 5.8: Bar graphs show pig mortalities in different houses before and during 2022 ASF outbreak

- Pig categories are denoted as letters which include: A=Sows; B=Boars; C=Growers; D=Finishers; E=Gilts; F=Sucklings; G=Weaners.
- Number of live and dead are denoted as: NBD=Number of live pigs available just before suspected ASF outbreak; NOD=Number of pigs which died during ASF outbreak.
- Weeks of year 2022 denoted as 14 through 30 represent seven dates such as: 14=10th – 16th April; 15=17th – 23rd April; 16=24th April – 31st April; 17=1st – 7th May; 18=8th – 14th May; 19=15th – 21st May; 20=22nd – 28th May; 21=29th May – 4th June; 22=5th – 11th June; 23=12th – 18th June; 24=19th – 25th June; 25=26th June – 2nd July; 26=3rd – 9th July; 27=10th – 16th July; 28=17th – 23rd July; 29=24th – 30th July; 30=1st – 7th Aug.

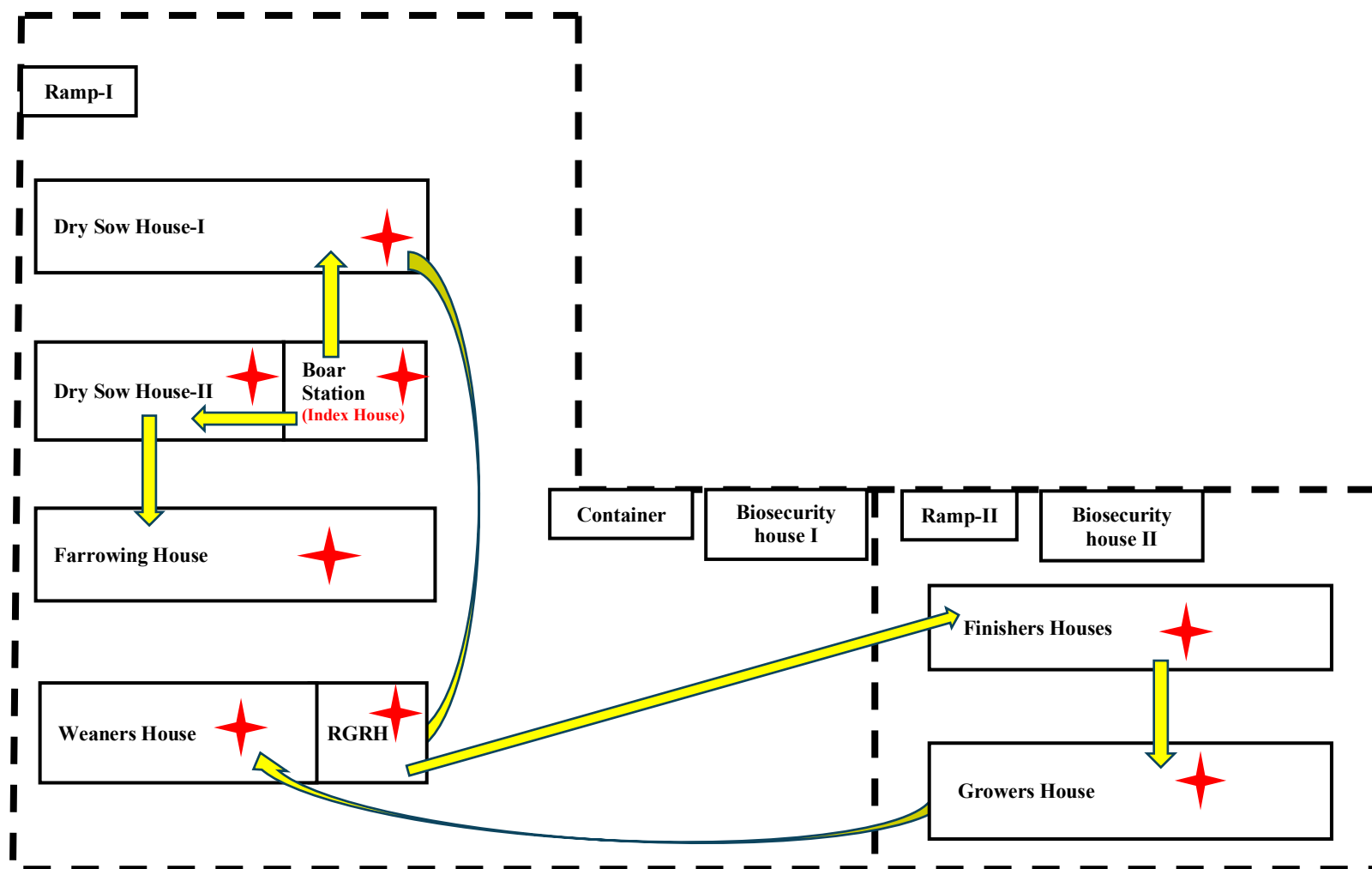


Figure 5.9: Schematic drawing death of pigs (denoted red star) in pig houses and direction of ASFV spread (denoted yellow arrow) across pig houses during 2022 ASF outbreak
Dashed line is a running in fence made of chain link wire.

5.6.3.4 Introduction of ASFV to the IMF in 2022 outbreak

In Figure 5.10, the descriptions for Ramp-I, Ramp-II, Container, and Biosecurity House I remains the same as in section 3.2.4, except for Biosecurity House-II (see section 2.3 Farm layout) was workers' entry points into Growers Section which was created after 2021 ASF outbreak. Biosecurity Houses II serves the same purpose as for Biosecurity House I described in section 3.2.4. Pig houses in production unit were linked to the mentioned five potential risk structures which connect pig houses to the outside. In 2022, "early infection" referring to sudden increase in deaths from week 15 through week 17 (see Figures 5.9 and 8.10) occurred again in DSH1, Boar Station and RGRH, but with Boar Station being an index pig house. Ramp-I, Container, and Biosecurity were being near to one or two of the three "early infection houses". The odds ratio of 'being early infected' in relation to the different locations are shown in Table 5.2. There were significant associations ($P < 0.001$) with all the three potential risk areas

Table 5.2: *The odds ratio (OR) for three pig houses in different locations being "early infected" on IMF investigated in 2022*

Potential risk areas	OR	95% CI		P value
		Lower	Upper	
Ramp-I	0.25	0.12	0.53	<0.001
Container	3.97	1.90	8.30	<0.001
Biosecurity House-I	24.75	5.52	111.06	<0.001

5.6.3.5 Feed samples test

A total of 60 samples collected from 12 different feed categories were tested for ASFV presence during the 2022 ASF outbreak, see Table 5.3. The feed categories included seven and five that were sampled directly from IMF and the feed milling company, respectively. Feed samples tested positive for ASFV on two of 32 attempted dates. Both positive samples were from feeds delivered to IMF in bulk form.

5.6.4 Other possible sources of ASFV introduction in 2021 and 2022 outbreaks

During the investigation, possible sources and routes of introduction were identified. five groups could be identified, see Table 5.4.

Table 5.3: Laboratory test results for feeds samples during the 2022 ASF outbreak in IMF

Sampling dates	NUMBER OF TESTED FEED CATEGORIES FROM IMF							NUMBER OF TESTED FEED CATEGORIES FROM FEED MILL					Total
	Gestation/ Boar Feed (*)	Grower Feed (*)	Lactation Feed (*)	Pellets/ Finisher feed (*)	Weaner Feed (*)	Premix (**)	Wonder Pig Row (**)	Coarse Powder (***)	Dust (***)	Maize Seeds (***)	Soya Bean Meal (***)	Wheat Bran (***)	
28/4/22	2(1+)												2
30/04/22				4				1	1	1	1	1	9
02/05/22				1	1								2
05/05/22					1								1
06/05/22		1											1
09/05/22						1	1						2
11/05/22										1	1		2
13/05/22	1			1(1+)	1								3
16/05/22		1	1	1	1	1				1			6
17/05/22		1											1
19/05/22				1	1								2
20/05/22		1											1
23/05/22		1			1	2				1			5
24/05/22					1								1
25/05/22		1											1
27/05/22		1											1
29/05/22					1								1
30/05/22			1										1
31/05/22		1											1
01/06/22		1				4							5
04/06/22					1								1
06/06/22		1											1
08/06/22		1											1
10/06/22		1											1
14/06/22		1											1
16/06/22		1											1
17/06/22		1											1
20/06/22		1											1
22/06/22		1											1
28/06/22		1											1
30/06/22		1											1
04/07/22		1			1								1
Total	3	20	2	8	9	8	1	1	1	4	2	1	60

(..+)=Number of positive samples

(*)=Feeds delivered to IMF in bulk; (**) =Feeds delivered to IMF in bag; (***)=Feeds not delivered to IMF

Table 5.4: Possible sources of ASFV introduction in the IMF

ASFV introduction risk	Existing biosecurity routines protocol	Identified possible biosecurity breaches in IMF
Contaminated vehicles	Vehicle disinfection areas within red zone near farms' main gate: Used for disinfection of all vehicles entering and leaving the farm Vehicle disinfection area within red-zone at entrance into biosecurity level: Used for disinfection of all vehicles entering and leaving biosecurity level-1	High risk vehicles such as those that deliver feeds, return after delivering carcasses, come to buy grower/gilts or deliver weaner pigs can introduce ASFV if not disinfected thoroughly before entering premises. Frequency of vehicle entry per week 1. IMF's Vehicles: a) Brings feeds from feed manufacturer 4-5 times. (Bulk feeds: through vehicle disinfection areas to silos where feeds are offloaded. Bagged feeds: through vehicle disinfection areas to container where feeds are offloaded). b) Delivers pork/carcasses to suppliers in town 5-6 times. Packs carcass from abattoir, passes through vehicle disinfection area near the main gate and to suppliers and returns back following the same path). c) Farm-workers' vehicles enters (6-7 times) through vehicle disinfection area near the gate and remains within red zone. d) Brings piglets purchased from farmers after every four weeks (monthly), enters through vehicle disinfection areas, proceeds to offload at "loading and offloading ramp into an IMF trailer. 2. Farmers' vehicles: a) Enter IMF every Saturday to buy Gilts. Pass through vehicle disinfection areas to loading/offloading ramp at where gilts are loaded on it.
Contacts with contaminated persons	"Dirty team" (e.g. abattoir and truck workers) to avoid contact with "clean team".	Dirty clothes and boots not changed and/or poorly disinfected. Contact made between dirty and clean teams.
Contaminated feeds	Observe biosecurity protocols while handling feeds on transit from mill to designated points in the farm where feeds are offloaded. At farm, bagged feeds offloaded on a biosecurity container should be disinfected before transfer to production unit.	Feed contamination could have occurred at feed mill or during transportation between feed mills and farm. Poor disinfection of bagged feeds at the container. Poor hygiene of tarpaulin used to cover unbagged feeds loaded in tractor trailers.
Workers and visitors entering farm with contaminated boots, clothes or hands	Farm workers and visitors accessing biosecurity level 1 and 2 should observe biosecurity protocols set in "Dry Shower House", "Biosecurity House 1, and "Biosecurity House 2".	Workers and visitors not observing biosecurity protocol.
Jealous neighbors	Their pigs shouldn't mix with farm pigs. They shouldn't access pigs in the farm.	Neighboring farmers intentionally selling ASF sick weaners to IMF

5.7 Discussions

Understanding of ASFV introduction into and spread within a farm is important for deeper understanding of the epidemiology and for designing effective prevention and control measures. The established index cases' dates of deaths and the laboratory diagnosis supported presence of ASFV in the farm during both the 2021 and 2022 outbreaks. However, the most likely sources of ASFV introduction into the farm could not be identified. IMF own trucks and farmers trucks coming from outside could have posed major risk of ASFV introduction to IMF. These trucks were most likely enough for virus introduction to IMF. The frequent entries per week of farmers' vehicles that enter IMF to buy pigs, and IMF trucks that deliver farm inputs such as feeds and or return back from purchases of growers pigs or from supply of farm products such as pork increase the chances of IMF exposure to ASFV contaminated vehicles and hence the ASFV introduction if they are not thoroughly cleaned and disinfected at the gate. IMF truck workers returning from the field engaged in offloading and or loading farm products could have been exhausted more than colleagues working within production unit, thus they were more unlikely to observe strict biosecurity measures of thorough cleaning, and disinfection of trucks and themselves at the gate. A study elsewhere revealed that workers in more than 72% of commercial farms do not change boots as they return to farms from loading pigs in the field (Li et al., 2019). Such field workers have high potential of introducing ASFV into the farm. Previous studies reported less than 50% of pig commercial farms disinfect vehicles returning from outside (Li et al., 2019), although all trucks or vehicles arriving from outside should be thoroughly cleaned and disinfected before entering the farm (Viltrop et al., 2021) to reduce the chance of introducing ASF.

Based on the epidemiological study of 2021 outbreak investigated within IMF, the suspected death of a sow on 12th May 2021 (week 18) which followed death of two sows on 6th May 2021 (week 17) suggest that, the ASFV might have infected the first sow earliest on 19th April 2021, relating to incubation periods of 4 – 19 days and death in 4 – 10 days after first clinical sign was observed according to Sánchez-Vizcaíno et al. (2012). This was supported by the fact that no death occurred in sow group for over five weeks prior to week 17, but later there was sudden increased deaths from week 19 to week 20. The relatively moderate number of deaths noted in other pig groups (suckling piglets, weaners, growers and finishers) for over four weeks, before week 17, and with no sudden increase in deaths was unlikely to have been caused by ASFV.

In 2022 outbreak investigation, the death of index boar on 17th April 2022 (early week 15), and no deaths recorded for over seven weeks before week 17 indicates the likelihood of first boar being infected around 1st April 2021. ASF effect slightly increased boar deaths from week 15 to week 16. Although there was slight increase in sow deaths in late week 15 (on 21st April 2022) and sharp increase in week 16 typical of ASF infection, the relatively small number of dead sows and other pig groups (suckling piglets, weaners and growers) which occurred for over six weeks prior to confirmed ASF outbreak, and with no sudden increase in dead numbers, indicated earlier deaths were unlikely caused by ASF.

Confirmations of ASF outbreaks in both 2021 and 2022 occurred in breeding section of production unit, particularly in Dry Sow Houses hosting gestating sows and breeding boars. Within Dry Sow Houses, in this context composed of two blocks (see figure 2), the identification of index cases of a sick sow in first block (DSH-I) during 2021 outbreak, and a dead boar during 2022 outbreak in Boar Station next to DSH-II, all are located within the second block, suggest some existing activities associated with ASF introduction possible in Dry Sow Houses more than others houses in Breeding Section and all houses in Growers Section. Potential access areas of ASFV introduction to production unit, such as Ramp-I, Ramp-II, Container, Biosecurity House-I and Biosecurity House-II are illustrated in Figures 5b and 8b. Of the three possibilities (Ramp-I, Container and Biosecurity House-I) associated with ASFV introduction due to “being near to” early infected pig houses (DSH-I, Boar Station and RGRH), only Ramp-I (7 meters from DSH-I) was most likely since workers of production unit come in contact with the IMF trailer while loading and offloading pigs, but there was no provision for cleaning and disinfecting workers after that exercise.

In addition, there was strong association ($P < 0.001$) between Ramp-I location and number of deaths in ‘early infected pig houses. Although IMF trailer which operates only within biosecurity Level-I never entered the production unit, the driver or trailer still could have picked pig excrement or contaminated fomites in the process of loading pigs into or offloading from farmers’ trucks packed in red-zone and ASFV were brought unintentionally to Ramp-I, making farmers’ truck – IMF trailer – “Ramp-I” pathway the most likely routes of ASFV introduction. Pigs from breeding section destined for slaughter at IMF abattoir were loaded onto IMF trailer from Ramp-I, the cleaning and disinfection of IMF trailer at abattoir, no direct contact with abattoir waste nor had access to Breeding Section; thus, the risk of virus introduction through IMF abattoir – IMF trailer – “Ramp-I” pathway was considered

negligible. Furthermore, “IMF feeds’ transports” especially bulk-trailers and refrigerated-trucks from outside, did not have access to production unit via the container (15 meters from boar station) where it delivered bagged feeds, although there was strong association ($P < 0.001$) between Container’s location and number of dead pigs in early infected houses, the disinfection of bagged feed inside the container before transfer to various feed troughs make ASFV introduction via IMF feed trucks – Container pathway unlikely.

Unbagged (bulk) feeds transported strictly in bulk trailer trucks was another risk factor of ASFV introduction into the farm due to vulnerability to contamination along the supply chain. Even though it was samples of unbagged feeds delivered to IMF that tested positive for ASFV, the possibilities of laboratory contamination or false positive could not be ruled out. The possible ways of unbagged feed contamination, suitable for indirect transmission, could have occurred during loading onto “IMF bulk trailer” packed at feed-mill or IMF truck workers along the way could have handled ASFV infective pork from roadside markets and used the same unwashed hands to touch feeds during offloading into urger filling machine located in biosecurity level-I, and that there was a likelihood of sampling from such feed consignment. Studies reported that ASFV can survive in plant based feed ingredients for 30 days under moderate temperate (mean 12.3°C) and humidity (mean 74%) conditions (Dee et al., 2018; Niederwerder, 2021). Fischer et al. (2020b), using field crops contaminated with infected blood, found that no viable virus was present after storage for 2 hours at room temperature, which would be higher in Uganda than in Europe.

The farm location being only 800 m away from Nakifuma town in the outskirts of Kampala city is a potential risk factor, considering that pigs slaughtered in Kampala are sourced from districts all over Uganda (Mwiine et al., 2019), where the ASF is endemic (Thomas et al., 2016; Mulumba-Mfumu et al., 2019). Regarding feeds sampled from the source (feed mill) with no positives and feeds already delivered to IMF, the few positives of laboratory detection of ASFV in delivered feeds suggests that contamination could have occurred along the supply chain after feeds were dispatched from the feed mill. However, inadequate farm records concerning vehicle movement, feeds, and other human activities weakened the source tracing. Available information provided was not enough to support the likelihood of feeds being a source of ASFV introduction into IMF, but the possible contamination of feeds sampled for laboratory analysis could have occurred from within IMF after the delivery of feeds.

Furthermore, the pig breeding process done within Breeding Section was regarded as a risk factor, triggered by the semen collection in Boar Station leading to a bi-weekly ‘closed loop’ pig movement, starting from AI Station as inseminated sows are moved to DSH-I and or DSH-II, movement of pregnant sows from DSH-I and or DSH-II to Farrowing House, and weaned sows transfer from Farrowing House and to AI Station for insemination. Gilts were also moved from RGRH AI Station for insemination. IMF using their own AI-technician and equipment may reduce likelihood of these activities leading to ASFV introduction, but the continuous sow movement for breeding process could have been a potential risk factor for internal ASFV spread. Although previous studies demonstrated that experimentally infected boars can shed ASFV in semen or seminal fluid (Maes et al., 2016; Friedrichs et al., 2022), it is unlikely that semen contributed to spread of ASFV within the pig production unit, since IMF had own AI technicians assigned strictly for AI service and own AI equipment were expected to be cleaned and disinfected before use in the next pig (boar or sow) during semen collection and insemination processes.

However, with early infected pigs (sow, gilts and boars) in both 2021 and 2022 outbreaks being a breeding pig group, the insemination processes which involved movement of pigs to and from AI station (e.g., m1, m2, m4 in figure 4 and m1, m2, m4, m6 in figure 7), AI technician from one pig to another, AI gun across pigs, and semen transfers from AI center to inseminate sows or gilts, all may pose high risk in the spread of ASFV within and across houses. There is no reliable evidence of sexual transmission of ASFV in the field (Bellini et al., 2016) in the case of semen. Movement of pigs, AI technicians and equipment were likely involved in transmission of ASF amongst boars, gilts and sows.

Pen-to-pen transmission was possible in some houses across materials used for pen separation. Metallic bar rails used for pen partitions in DSH-I and DSH-II were far enough apart to allow probable nose-to-nose contact, see Appendix 3.3. Likewise, aerosol transmission could have been possible between some pens (Wilkinson et al., 1977; Olesen et al., 2017). Additionally, movement of contaminated material such as equipment, and gumboots from pen to pen was another likely source of ASFV spread within pig houses. Confirmation of ASF presence in DSH-I on 12th, 16th, and 17th of May 2021 support the findings that ASFV could have spread through movement of contaminated materials and or pig to pig contacts via open spaces in partitions. According to previous research (Bellini et al., 2021; De Lorenzi et al., 2020), high levels of farm biosecurity including paying special attention to the disinfection process is

considered to be the most important tool for preventing ASF virus entering pig farms and spreading within the farm.

Death of seven sows within three weeks in one house (DSH-I) only in 2021 outbreak, and 95 dead pigs within three weeks in two Dry Sow House blocks (Sows=81, and Boars=14) in 2022 outbreak houses revealed slow spread of ASFV at the beginning of the two outbreak waves. This initial slow spread, as expected (Depner et al., 2017), is consistent with the challenge of achieving early detection of ASFV in commercial farms such as IMF (Li et al., 2020). Similarly, the detection of ASFV among sows in DSH-I and eventual increase in pig mortality within one month, shows the unlikelihood of workers complying with enhanced biosecurity measures to contain the virus, resulting in rapid spread of ASFV within and between houses. Previous study in smallholder pig farms reported high mortality within short period of time (Le et al., 2023).

Limitations: The use of secondary data such as dates of event occurrence, laboratory results, and pig inventory had some limitations. The researchers who analyzed such data are not the same persons as those involved in data collection, and sometimes the secondary data may miss details that are very important for data analysis, all of which could affect validity of results. Secondary data are not collected to answer researchers' specific questions (Boslaugh, 2009; Cheng & Phillips, 2015). Interviews with the farm director and veterinarian provided some missing and additional important information.

I conclude that in these two outbreaks, although the investigated IMF had excellent facilities and enhanced biosecurity measures to contain ASF within index houses and control its spread were promptly instituted, they were unable to prevent introduction and internal spread. The spread of ASFV was slow at the beginning of the outbreak. My investigation showed that human activities have most likely contributed to ASF virus entering and spreading in the commercial pig farm. Non-compliance with farm biosecurity measures provided gaps for virus introduction and spread within the farm. In addition, the orientation of structures in production unit as well as designs of inner fence and pig pens are key in ASFV introduction and spread in the farm. We recommend that critical sections of available biosecurity protocols such as at Ramp-I for offloading new pigs bought from farmers, thorough cleaning and disinfection at main gate for farmers and IMF trucks coming from out must be enhanced.

CHAPTER SIX: ACTIONS AND PERCEIVED ECONOMIC IMPACT OF ASF CONTROL MEASURES

This paper provides information on actions and perceived impact of ASF control measures along the smallholder pig value chain in Uganda. Its focus is on the quarantine imposed following outbreak of ASF.

The chapter investigated the following questions

1. What are the actions taken during period of quarantine imposition?
2. What are the perceived losses incurred during quarantine imposition?
3. Which value chain actors were affected most and why?

This chapter has resulted into:

Aliro, T., Odongo, W., Ståhl, K., Dione, M. M., Okello, D. M., Masembe, C., & Chenais, E. (2023). Actions and perceived impact of African swine fever control measures along the smallholder pig value chain in Uganda. *Tropical Animal Health and Production*, 55(6). <https://doi.org/10.1007/s11250-023-03828-5>

6.1 Introduction

The pig sector in Uganda is affected by several constraints that hinder its further development, including the endemic occurrence of African swine fever (ASF). ASF is a viral disease affecting domestic pigs and wild boar with a serious consequences, in most cases lead to massive death of pigs within one week after infection (Penrith et al., 2013). The sylvatic epidemiological cycle of ASF is present in Uganda, but as in most parts of the world, the disease spread is mainly occurring in the domestic pig epidemiological cycle (Penrith et al., 2019). ASF spread in the domestic pig cycle involves direct and indirect contact between naïve and infected pigs and pork products and is driven by human activities along the value chain such as slaughter and trade in live pigs and pork products. Transmission is exacerbated by low levels of biosecurity and the free range type of management that is common in most smallholder pig farming systems in Uganda (Chenais et al., 2017b).

Despite recent progress in ASF vaccine development, prevention and control of ASF is largely through biosecurity and outbreak management (Penrith et al., 2019; Dixon 2020). In Uganda, current ASF control measures include passive surveillance, trade and livestock movement restrictions, called quarantine, upon confirmation of outbreaks (Wesonga et al., 2018). While previous studies in Uganda have described ASF epidemiology, virology, biosecurity implementation and ASF impact at farm level (Chenais et al., 2017a; Chenais, 2017; Masembe et al., 2018; Ouma et al., 2018; Chenais et al., 2019a) less is known about the implementation of ASF control measures during outbreaks, as well as the impact of these control measures on the different stakeholders along the value chain. To improve ASF control, it is important to understand what stakeholders do during quarantine, and how not only the disease but also the control of the disease impact stakeholders. This study aimed at assessing actions taken by different stakeholders and the perceived economic impact during quarantine.

6.2 Material and methods

6.2.1 Study area

The study was conducted in 2019 in two districts, Moyo and Kisoro (Figure 6.1) in Uganda. Between 2015 and 2018, the veterinary authority in Uganda, Commissioner of Animal Health, imposed quarantine during confirmed outbreaks of ASF in two districts in Uganda. Restrictions were effective in Kisoro district from July 2015 to January 2016 and in Moyo district from March to November 2018. These two districts were selected since quarantine was imposed at

all nodes along the pig value chain in all sub-counties in these districts. Based on confirmed ASF cases, eight sub-counties were selected in Kisoro, and four in Moyo

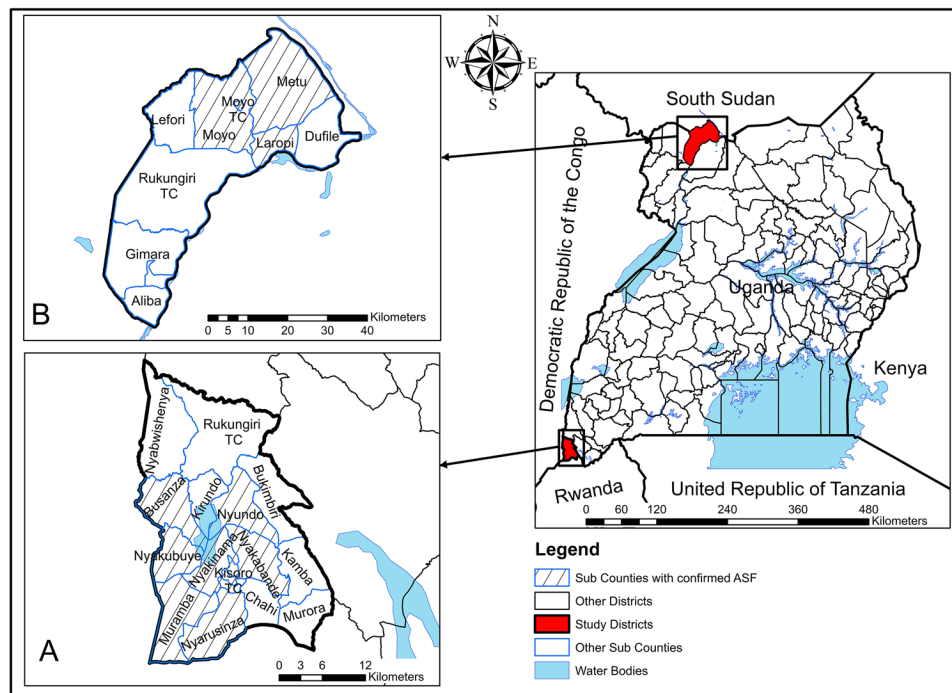


Figure 6.1: Maps of Kisoro (A) and Moyo (B) districts showing the sub-counties indicated red where data were collected
These maps were created using ArcGIS version 10.8.0

6.2.2 Data collection

The study applied participatory epidemiology tools in focus group discussions (FGDs) and key informant interviews (KIIs). The field research team was composed of the first author (TA) together with one facilitator and one notetaker for each district. The facilitator and the notetaker pair were both proficient in both English and local language (Rufumbira in Kisoro and Madi in Moyo). Both the facilitators and the notetakers had educational background in livestock production and management and were trained in qualitative and quantitative research approaches and the procedure for data collection prior to actual data collection. All interviews started with taking participants through the purpose of the study, explaining that participation was voluntary, and assuring confidentiality. Participants signed a written consent form to these effects.

6.2.2.1 Key informant interviews (KIIs)

The District Veterinary Officers (DVOs) of the study districts were selected as key informants (KIs) based on their knowledge of guidelines and policies on animal disease control, and for overseeing livestock disease management (surveillance, control and reporting) in their respective districts. The first author interviewed key informants (in English) before the first FGD was conducted in each district. This interview was done with the purpose of informing the FGD topic guides. The KIIs followed a checklist of topics regarding marketing of pig and pig products and sourcing of pig breeding stock (Appendix 6.1). The key informants were additionally asked to describe the local pig value chain, including pig market linkages and processes from producers to final pork consumers in their districts at the time of restrictions. Notes were taken on paper.

6.2.1.2 Focus group discussions (FGDs)

In each district, focus groups were constructed to be homogenous regarding the participants' role in the value chain (farmers, traders and veterinarians), but to include both men and women in each group (Tables 4.1 and 4.2). Two FGDs with farmers (hereafter called farmer FGDs and with group identity (ID) FGD1, 2, 6 and 7), two FGDs with other stakeholders in the value chain such as middlemen, butchers (fresh pork retailers) and pork-joint¹ owners (roasted pork retailers) (hereafter called trader FGDs and with group ID FGD3, 4, 8 and 9); and one FGD with veterinarians (hereafter called veterinarian FGDs and with group ID FGD 5 and 10) were held in each district. The groups included between four and 14 participants, a group size that was deemed optimal for active participation in the discussions (Krueger & Casey, 2000). Farmers were selected for the FGDs using predetermined inclusion criterion: that the farmer was a resident in a subcounty that had confirmed ASF during the restriction period, had pigs during the period of restriction, and that his/her pig herd was not affected during the restriction period. In addition to farmers, traders were selected for the FGDs using the following inclusion criterium: that the trader operated pig or pork business in one of the sub-counties that had confirmed ASF at the time of restrictions. Veterinarians who worked as livestock extension workers in the affected sub-counties during the restriction period were further selected for inclusion.

¹ "Pork-joints" are small kiosk-like restaurants serving only pork.

The discussion followed a topic guide which included imposed quarantine measures, perceived reasons for imposition, measures taken by actors in response to the restrictions, stakeholders perceived to be economically affected, and ranking of affected stakeholders according to the relative economic impact (Appendix 6.2). Ranking using proportional piling was performed as described by Mariner & Paskin (2000) for the topic of stakeholders that were affected economically. During the FGDs, the facilitator guided the discussion. This included asking participants what they thought about what other participants mentioned, if anyone disagreed or had different opinions to share. Different opinions were discussed, and consensus was sought. The FGDs were held in Rufumbira (in Kisoro district) and Madi (in Moyo district) with the facilitator translating to English, sentence by sentence. The first author asked probing questions if something was unclear and took detailed notes. Additional notes were taken by a notetaker. The FGDs lasted on average 80 minutes. Refreshments in the form of a soft drinks were served during the discussion. Participants were refunded transport expenses at the end of the discussions.

In each FGD, participants were asked to list the restriction measures included in the imposed quarantine. Every restriction measure mentioned by a participant formed the basis of discussion concerning why the participants thought the measure was imposed, and actions taken by the participants in connection to that measure.

Further, the participants identified all stakeholders who could have been affected economically by the quarantine. The facilitator listed these stakeholders on a flip chart sheet placed on the ground. In the next step, one participant was asked to distribute 100 beans between the listed stakeholders to reflect the perceived relative economic impact due to the quarantine. More beans were given to stakeholders perceived as having suffered more economic impact. All participants were encouraged to contribute to the discussion and in the decision for the final distribution of beans. The number of beans allocated to each stakeholder were counted, and the stakeholders ranked according to the number of beans, with the stakeholder receiving the highest number of beans ranked as number 1, and the stakeholder with the second highest number of beans ranked as number 2, and so on for all listed stakeholders. Stakeholders not listed in all the ten FGDs were not considered for analysis. After this, aspects perceived as causing these economic losses were listed for every mentioned stakeholder. This list formed the basis for a subsequent discussion on reasons for the ranking.

6.2.2 Data analysis

Immediately after the KII in each district, the first author (TA) performed a preliminary analysis of the data by reading through the notes and removing phrases that were repeated, and/or deemed irrelevant to the topic of discussion. After that the KII findings were used to improve the draft FGD topic guide. The notes from the two KIIs were compared to provide information regarding pig marketing from farmers to final consumers, existing local pig value chain, various market linkages and pig breeding that were similar and or different across the two districts.

On each day, at the end of FGDs, the first author and the notetaker compared their field notes, including participants' details (stakeholder category and gender) to create one final master note for each FGD. Based on these master notes TA and the fifth author (DMO) aggregated data from all the ten FGDs (Table: 1, 2, 3, 4 and 5). Actions taken were recorded and every action mentioned was recorded as mentioned or not mentioned for each FGD. Data referring to economically affected stakeholders ranked by participants in each FGD were merged to give the overall rankings across all ten FGDs. Data referring to perceived economic reasons for ranking stakeholders were recorded as the number of FGDs that mentioned a particular reason under the affected stakeholder. This procedure was done for all the perceived economically affected stakeholders.

6.3 Results

6.3.1 KIIs and FGD participants

In total, two KIIs were interviewed, and 77 participants were included in ten FGDs. The composition of the FGDs varied according to the stakeholders present in each study location. The majority (49/77) of FGD-participants and both key informants were men (see Tables 6.1 and 6.2).

Table 6.1: *Composition of participants in FGDs from a study performed in Moyo and Kisoro districts of Uganda in 2019*

District	Categories of participants in FGDs						Total
	Farmers	Butchers	Butchers & PJO	PJO	Middlemen	Veterinarians	
Moyo	22	0	6	1	2	5	36
Kisoro	27	1	4	2	3	4	41
Total	49	1	10	3	5	9	77

FGDs=Focus group discussions; PJO=Pork joint owner

Table 6.2: *Characteristics of participants in an interview study performed in Uganda in 2019*

District	Group identity	Male	Female	Total
Moyo	FGD1 (Farmers)	7	3	10
	FGD2 (Farmers)	8	4	12
	FGD3 (Traders)	3	1	4
	FGD4 (Traders)	5	0	5
	FGD5 (Veterinarians)	4	1	5
	KII-1 (DVO)	1	0	1
Kisoro	FGD6 (Farmers)	5	9	14
	FGD7 (Farmers)	6	7	13
	FGD8 (Traders)	5	0	5
	FGD9 (Traders)	3	2	5
	FGD10 (Veterinarians)	3	1	4
	KII-2 (DVO)	1	0	1
Total		51	28	79

6.3.2 Key Informant interviews

According to the respective KIIs, Moyo district did not have any livestock markets at the time of quarantine imposition whereas Kisoro district had weekly livestock markets in two different locations. Unsold pigs would be taken back home by farmers from both livestock markets. Furthermore, pigs bought from livestock markets in Kisoro and at farm-gates in both districts would sometimes be sold in neighbouring districts and countries. Pigs bought for slaughter from livestock markets (in Kisoro) and farm-gates (both districts) were either slaughtered at designated slaughter slabs or within pork joint premises. Consumers in both districts could access fresh pork from pork-kiosks (butcheries) and pork-joints. In both districts, farmers acquired breeding stock from fellow farmers.

6.3.3 Focus group discussions

According to the participants in both farmers and traders FGDs, the ban on trade and movement of pigs and pig products and pork consumption were the imposed quarantine measures. Several actions were taken by the stakeholders in response to the imposed quarantine measures (see Table 6.3). These actions and the corresponding measures are described for each of the actors in the subsequent sections.

Table 6.3: Action taken in response to African swine fever (ASF) quarantine

Actors	Imposed restrictions	Actions taken by participants	FGDs mentioning action taken			
Farmers (49 participants)			FGD1	FDG2	FGD6	FGD7
	Ban on pig trade	Did not buy pigs				
		Did not sell pigs				
		Sold pigs				
	Ban on pig movement	Confined free range pigs				
		Did not allow movement of boars for breeding purpose				
		Used boda-boda to cross national borders				
		Used boda-boda to carry pigs across international borders				
		Delivered pigs to a trader who bought a pig				
	Ban on pork movement and consumption	Did not slaughter pigs				
		Slaughtered pigs at home				
		Could not access pork for home consumption				
		Accessed pork for home consumption				
	Safe carcass disposal	Reported cases of dead pigs to DVO so that carcasses could be collected for burning at designated point				
	Traders (19 participants)			FGD3	FGD4	FGD8
		Bought pigs from farmers				
		Bought pigs at night				
		Sold pigs to fellow butchers who could not buy from farmers				
		Sold pigs within and beyond the district				
		Sold pigs across international borders				
	Ban on pig movement	Moved pigs across national & international borders				
		Moved pigs on boda-boda across international borders				
		Moved pigs and pork along community village roads				
		Move pigs to clients				
		Moved fresh pork to clients				
		Moved pigs at night				
	Ban on pig slaughter	Did not slaughter pigs				
		Slaughtered pigs outside designated slaughter slabs				
		Slaughtered pigs at farmers' home				
		Slaughtered in the bush				
		Slaughtered at night				
	Ban on pork trade	Accessed and ate pork away from home				
		Accessed pork for home consumption				
		Accessed pork for home consumption from neighbouring district				
		Did not roast pork				
		Roasted chicken and fish as pork substitute.				
		Relocated pork roasting business to neighbouring district				
Veterinarians (9 participants)					FGD5	FGD10
	Enforce ban on pig/pork trade and movement	Sent awareness message through radio announcement & display in public place				
		Denied pigs business in livestock markets				
		Did not issue animal movement permit				
		Withdrew movement permit booklets from extension workers				
		Suspended inspection of pork				
		Crime-preventors joined veterinarians in enforcing trade ban				
	Intensification of disease investigations	Collected carcasses from farmers				
		Performed surveillance visits in sub-counties near district headquarters				
		Performed surveillance visits in sub-counties with confirmed ASF outbreak				

FGD=focus group discussion; DVO=district veterinary office; Green cells=At least one participant in a FGD mentioned that action; Yellow cells=No participants in a FGD mentioned that action

6.3.3.1 Farmers

Fourteen different actions were mentioned in the farmer FGDs in response to the restrictions on trade and movement of pigs and pig products. Participants in three of the four farmer FGDs reported that farmers did not buy pigs (breeding stock) during the restrictions period. Continuous sales of pigs to traders were mentioned in all the farmer FGDs. Participants in one of the four farmer FGDs (FGD1) reported to offer traders to slaughter pigs at their homesteads

during the quarantine period. It was further mentioned that pigs were transported from farmers' home using boda-boda².

6.3.3.2 Traders

Twenty-four different actions were mentioned in the trader FGDs in response to the quarantine restriction. Participants mentioned that during the quarantine period some traders avoided pig transactions in livestock markets and instead performed pig trade at farmers' homesteads. Participants further reported having sold pigs and pig products both within the two districts and beyond district and country borders. Both live pigs and pig products were transported from farmers' homesteads to clients using boda-boda. Participants reported that no pigs were slaughtered in slaughter slabs, and all the pork joints were un-operational during the quarantine period. Several participants mentioned that farmers' homesteads were used for slaughtering pigs instead of slaughter slabs. Traders further reported that consumers were buying pork from some traders despite closure of slaughter slabs, butcheries and pork joints.

6.3.3.3 Veterinarians

Six different actions taken to enforce the ban on pig trade and movement were mentioned in the veterinarian FGDs. Participants reported that pig trading was not carried out in any of the livestock markets and movement permits were not issued to pig traders during the quarantine period. They further mentioned involvement of crime preventers³ in the enforcement of restrictions in livestock markets to ensure that no pigs accessed the markets. Participants said that they had conducted surveillance visits in sub-counties with ASF outbreaks to check if traders closed their business premises (such as slaughter-slabs and pork joints) as obliged, and to get a better understanding of the epidemiological situation.

6.3.4 Perceived impact of quarantine measures on stakeholders

6.3.4.1 Farmers

Overall, farmers were perceived to be the most affected stakeholder; ranked first by three out of four farmer FGDs, two out of four trader FGDs, and both veterinarians FGDs (see Table 6.4). Impacts mentioned in all FGDs included revenue foregone when marketable pigs could

² "Boda-Boda" is a common term in East-Africa for motorcycle used as taxi for carrying passengers or goods

³ "Crime preventers" are volunteer force of civilians recruited and managed by police to report on and prevent crime in cooperation with the police and communities in Uganda

not be sold and the additional cost of feeding marketable pigs during the quarantine period. Additionally, costs associated with constructing temporary pig shelters, feeding of the pigs that would have been managed on free-range if restrictions had not been in place, and the opportunity cost foregone of selling pig manure were mentioned by participants in the four farmers' FGDs.

Table 6.4: *Ranking of stakeholders according to the perceived impact of African swine fever quarantine in two districts of Uganda*

Group Categories.	Group Identity	Ranking* of the affected stakeholders					
		Farmers	Middlemen	Tax-collectors	Butchers	Consumers	Veterinarians
Farmers	FGD1	1	4	2	3	6	5
	FGD2	1	3	4	2	5	6
	FGD6	1	3	6	2	5	4
	FGD7	2	3	6	1	4	4
Traders	FGD3	3	2	5	1	4	6
	FGD4	1	4	5	2	2	6
	FGD8	2	3	5	1	6	4
	FGD9	1	4	3	2	6	5
Veterinarians	FGD5	1	2	3	3	6	3
	FGD10	1	3	6	2	4	5
Sum of ranking scores		14	31	45	19	48	48
Overall ranking		1	3	4	2	5	5

*Ranking 1=most affected stakeholder, 5=least affected stakeholders: FGD=focus group discussion

6.3.4.2 Butchers and pork joint operators (pork retailers)

Pork retailers were perceived to be the second most affected stakeholder, being ranked either in first or second position by three out of four farmer FGDs, all four trader FGDs and one of two veterinarian FGDs. According to participants across all FGDs, failure to acquire pigs from farmers as well as loss of income from pigs and pork sales was perceived as negatively affecting business of butchers and pork joint operators when markets, pork butchereries and pork joints were closed. Losses due to advance rental payment for business premises, and cost of relocating pork-roasting businesses to neighboring districts were mentioned by all four traders FGDs (see Table 6.5). A participant in FGD2 exemplified this; “*Big, big loss by pork roasters as they never attempted to roast in fear of people detecting smell and smoke from pork joints*”.

6.3.4.3 Middlemen

The overall economic impact of quarantine on middlemen was reported as small compared to farmers and pork retailers. Participants in nine FGDs perceived that middleman had lost income from sale of pigs and commission for mediating pig sale transactions between farmers and

butchers during the restriction period (Table 6.5). Participants noted that middlemen normally make their business from buying pigs from farmers and selling to butchers, or payments are received from both farmers and butchers for linking transactions. Two traders and one veterinarians' FGDs perceived that middlemen were affected as money that were paid in advance for renting pig holding facilities that remained non-operational during the restriction period could not be recovered.

6.3.2.4 Tax-collectors

Sellers and buyers of pigs pay market-dues and loading fees in livestock markets. Five FGDs (two farmers', two traders', and one veterinarians' FGDs) mentioned that the collectors of these fees at the livestock markets were affected by the imposed quarantine. The perceived losses of pig slaughter-fees were reported by six FGDs (all four traders' s and all two veterinarians' FGDs) to have affected tax-collectors when slaughter slabs and pork joints were closed. It was reported that even when the quarantine was lifted, tax-collectors were not reinstated to complete their task.

6.3.2.5 Consumers

Consumers and veterinarians were considered the least affected stakeholders, ranked in either fifth or sixth positions by three out of four farmer FGDs, all four trader FGDs and both veterinarian FGDs. All FGDs reported that consumers incurred additional cost for buying substitute for pork (fish and chicken) that was more expensive, and six (four farmers and two traders FGDs) mentioned costs for hiring boda-boda riders to search for pork. The price of pork bought illegally was perceived to be higher than the normal pork price by two farmers and two traders FGDs.

Table 6.5: *Perceived economic losses due to imposed restriction measures on stakeholders*
FGD=focus group discussions

Affected stakeholders	Areas of economic impact	Number of FGDs that mentioned (n=10)
Farmers	Forgone revenue for pig sales	10
	Cost incurred for feeding unsold pigs	10
	Cost for biosecurity measures	7
	Cost for veterinary payment	6
	Foregone revenue for boar hire	5
	Cost incurred for feeding confined (instead of free-range) pigs	5
	Foregone revenue for manure sales	4
	Cost for constructing shelter for confining free-range pigs	4
	Cost for pigs' requirements	4
	Loan servicing	4
	Cost for buying local concoction for treatment of pigs	1
	Cost for waste disposal	1
Butchers and pork joint operators (pork retailers)	Foregone revenue for live pigs and pork sales	10
	Cost for rent of business premises	5
	Cost for relocating business across border	4
	Payment to farmers for pigs bought on credit	4
	Cost for feeding unsold pigs	3
	Unrecovered money for trading license	3
	Foregone revenue for fresh pork that staled in the fridge when the facility was suddenly closed	2
	Loan servicing	2
	Foregone revenue for swill or leftovers sales	1
	Cost for loan for alternative businesses	1
Middlemen	Foregone revenue for pig sales	10
	Loss of revenue as commission payment from butchers	9
	Cost for pigs that died in confinement facility	5
	Loan servicing	5
	Rent for live pig holding facility	3
	Violation fine (when defied the laws)	1
Tax-collectors	Forgone slaughter fee	8
	Foregone market due fee	5
	Foregone market loading fee	5
	Cost for maintaining slaughter slab premises	5
	Foregone release fees collections along highways	3
	Loss of commitment-fee	2
	Cost for paying workers' salary	2
	Payment for mandatory medical check-up	1
Consumers	Cost for pork substitute	10
	Cost for pork bought illegally	7
	Cost for hiring boda-boda drivers to buy pork across border	6
	Cost for pork bought across border	2
Veterinarians	Foregone pork inspection fee	5
	Foregone movement permit fee	5
	Cost for quarantine enforcement	5
	Loss of pig treatments revenue	4
	Cost for sensitizing the general public	4
	Foregone live pig (market) inspection fee	3
	Cost for carcasses collection	3
	Cost for carcasses disposal	3
	Loss of drugs sales revenue	2
	Cost for sample collection	2

6.3.2.6 Veterinarians

Three traders and both veterinarians FGDs mentioned that veterinarians lost fees for pork inspection, pork quality assurance at slaughter slabs and movement permit for health certification of pig on transit. The foregone cost of inspection fee for ante-mortem examination of live pigs in livestock markets was perceived as affecting veterinarians by two traders and one veterinarian FGDs. Costs of fuel for collecting pig carcasses from farmers and burning carcasses at district head quarter incurred by veterinarians was mentioned by two farmers and one veterinarian FGDs.

6.4 Discussions

The study assessed actions different stakeholders took and the perceived economic impact during quarantine imposition. While the restriction measures seemed to be largely observed in the formal market spaces, a concurrent shift from formal market settings to more informal, non-regulated settings were described, suggesting that the regulatory authorities only managed to enforce quarantine in the formal marketplaces. Continuous trade in live pigs and pig products has previously been reported as common during ASF outbreak and subsequent quarantine in Uganda (Chenais et al., 2017b; Dione et al., 2017b; Okello et al., 2022). Another study pointed to lack of capacity to enforce existing regulation as a key constraint in implementing ASF quarantine (Wesonga et al., 2018).

With trade moving from formal to informal markets, stakeholders do not pay any fees (mandatory movement permit fees, slaughter fees and carcasses quality certification fees) that are collected by the public veterinary personnel. These fees are legally stipulated in the Public Health Act (Laws of Uganda 1935), Cattle Traders Act (Laws of Uganda, 2000) and the Animal Diseases Act (Laws of Uganda 2006), and the incomes were reported as foregone for the tax collectors. In Uganda, the incomes generated from mandatory certification are used to sustain the continuity activities and form part of the salary for the public veterinarians as the allocated budget often are inadequate (Ilukor, 2018). During the quarantine, the role of the regulatory authorities thus changes from facilitation of movement and providing certification to inhibiting the same.

Animal disease control measures associated with negative economic impact that is not accompanied by compensation is bound to non-compliance (OIE, 2014). In Uganda, farmers

are not compensated for loss of pigs due to ASF outbreaks, therefore reporting suspected outbreaks are mostly non-beneficial to farmers. Denying farmers the opportunity to sell livestock and the lack of compensation make the implementation of quarantine unpopular among other stakeholders including political leaders who can lift quarantine as incentives to appease their voters (Ilukor et al., 2015a).

Many smallholders in east Africa rely on pigs as the main source of revenue, with pig sales financing critical household needs such as school fees and healthcare (Mutua et al., 2011; Muhanguzi et al., 2012). Poor people such as most smallholders in the study area are more vulnerable to regulations such as quarantine following animal disease outbreak (Wagstaff, 2006). Because of their vulnerability and high dependent on the pigs, the smallholders prioritize continuation of the pig business even during quarantine.

While the impacts associated with livestock disease outbreaks and control affect actors all along the value chain in some ways (Rich & Wanyoike, 2010), the impact is not the same for all stakeholders, depending on among, other things, livestock contribution to their livelihood (Rich & Perry, 2011). In this study economic impact of quarantine was perceived to be higher among farmers and pork retailers. According to the results, traders seemed to be less affected by quarantine than farmers, because the traders relocate their business to areas without quarantine. Previous studies have further reported of traders making profit during ASF outbreaks by buying pigs cheaply and selling pork at normal market price (Chenais et al., 2017b). This is exacerbated as smallholders lack a common voice in pig trade (Ouma et al., 2016). In Uganda, over 70% of pork is consumed at pork joints (Roesel et al., 2019). Consequently, quarantine restrictions were perceived as causing revenue losses affecting pork retailers. In this study, the continued trade and slaughter of pigs however implied consistent consumer demand.

This study had some limitations that must be pointed out since they could affect the interpretation and application of the findings. First, there was an unbalanced gender distribution among the participants. Although men often decide on how to allocate resources for biosecurity, women play a key role in pig management (Ouma et al., 2015) and have substantial autonomy on daily expenses, and high bargaining power for family business (Agarwal, 1997). Thus, the selection bias with underrepresentation of women could have affected the results. Second, the study was conducted in 2019 but concerned quarantine that was imposed between 2015 and 2018. Consequently, recall bias might have been present (Raphael, 1987). To avoid

this, future studies could be conducted immediately after a quarantine to allow for close-to-real time assessment of economic impact of the quarantine. Lastly, loss of information or depth could have occurred as the FGDs were conducted with the help of translators (Rufumbira in Kisoro district; and Madi in Moyo district) (Fischer et al., 2020a). However, selecting bilingual facilitators that were resident veterinarians in the districts, with broad experience in activities along pig value chain, and triangulating data with the facilitators post-interview helped to overcome this potential bias.

CHAPTER SEVEN: THE ECONOMIC IMPACTS OF ASF-INDUCED QUARANTINE IN SMALLHOLDER PIG VALUE CHAINS: A SYSTEM DYNAMICS APPROACH

This paper provides information of economic impact of controlling ASF along the smallholder pig value chain in Uganda. Its focus is on quarantine imposed following outbreak of ASF. The chapter investigated the following questions:

1. What are the actions taken during period of quarantine imposition?
2. What are the perceived losses incurred during quarantine imposition?
3. Which value chain actors were affected most and why?

7.1 Introduction

Uganda is a low-income country with high potential for developing its livestock industry (Wabukala, 2018). A particular area for focus is the pig sector, whose rapid growth over the past 15 years has had benefits for poverty alleviation and contributes to national food security and livelihood income for many people (Ouma, 2014; Ouma et al., 2017; Sentumbwe, 2017). The 123% increase in the national pig population from 3.2 million in 2008 to 7.1 million in 2021 (UBOS, 2024) has been fueled by increasing high pork demand over the past years (Ouma et al., 2017). Uganda is ranked highest in East Africa and third in Africa after Nigeria and South Africa in its pork consumption, with an average annual per capita pork consumption of 3.4 kg (FAO, 2018). According to Twine & Njehu, (2020), the pig sector in Uganda largely serves the domestic market, despite the high potential for regional trade to nearby markets. In 2015, Uganda officially exported 167 tones of pork to neighboring countries such as South Sudan, Rwanda, and the Democratic Republic of Congo (DRC), though it is likely that informal exports are higher.

However, the potential of the pig industry has been threatened by outbreaks of diseases such as African Swine Fever (ASF). ASF is viral disease belonging to the family *Asfviridae*, characterized by rapid spread and a mortality rate approaching 100%. Over the past two decades, ASF has remained endemic in Uganda (Atuhaire et al., 2013; Kabuuka et al., 2024) and other African countries, (Mulumba-Mfumu et al., 2019). Without the existence of an effective ASFV vaccine, implementation of pig movement restrictions and strict biosecurity measures at all levels in the pig value chain are essential in the prevention and control in countries like Uganda where ASF is reported (Martínez et al., 2021; Penrith et al., 2023).

The economic impact of ASF has attracted global attention, as outbreaks result in significant direct and indirect losses to the pig industry, making it economically devastating in countries with highly industrialized pig farming as well as in those countries with small-scale or backyard pig production (FAO and OIE, 2021). In Africa, although ASF affects both large scale commercial and smallholder pig producers, the heaviest losses are inflicted on the more resource constrained pig producers who are unlikely to effectively implement practices such as foot baths and hand washing (Edelsten & Chinombo, 1995).

Given the poor implementation of biosecurity measures that make farmers more susceptible to ASF outbreaks and subsequent pig deaths, the poor farmers are further pushed into poverty, as

ASF outbreak reduces household income and availability of cheap protein. This further reduces farmer capacity to pay expenses like school fees and medical bills (Chenais et al., 2017; Smith et al., 2019). Qualitative economic impact assessments previously conducted in Uganda have described the failure of families to achieve their livelihood requirements following the loss of their income source from pigs (Chenais et al., 2017); the unwillingness of farmers to restock new pigs and invest in biosecurity, due to fears of future disease reoccurrences (Chenais et al., 2019; Arvidsson et al., 2023); and perceived relative monetary losses incurred during quarantine imposition (Aliro et al., 2023). Direct economic impact studies conducted in Uganda considered the estimation of mortality rates (average of 80%) from ASF cases (Dione et al., 2014; Chenais et al., 2017; Ekakoro et al., 2023). Ouma et al. (2018) estimated that investments in farm biosecurity would reduce ASF incidence and farm-level profit margins by 8% but raise traders profit margins by 6.2% due to more stable pig supplies.

One of the gaps in ASF research is the lack of quantitative studies that consider the economic impact of implementing control methods at all nodes in smallholder pig value chain following confirmed disease outbreaks (Penrith & Kivaria, 2022). In Uganda, Ouma et al. (2018) reported variations in economic impacts across different value chain actors following on-farm biosecurity investment to control ASF outbreaks. The involvement of different actors in assessing economic impact of ASF control intervention, in this context, implementation of disease policy intervention along value chain during ASF outbreak, can provide key impact parameters suitable for designing a safe and profitable control strategies.

In this study, we assessed the cost-benefits of different policies and enhanced biosecurity interventions along smallholder pig value chain in Moyo district, Uganda. Of particular emphasis is the epidemiological and economic benefits of control interventions in which livestock markets were closed to prevent the further spread of ASF.

7.2. Methodology

7.2.1: Descriptions of study area and available pork processing facilities

This study was conducted in May and June 2024 in Moyo district in Uganda. Moyo District is bordered by South Sudan to the north and east, Adjumani District to the south, across the waters of the White Nile, and Yumbe District to the west (Figure 7.1). In 2018 and 2022, the veterinary authority in Uganda, Commissioner of Animal Health, imposed quarantine restrictions during confirmed outbreaks of ASF in Moyo district. Restrictions were in effect in Moyo district from March to November 2018, and from October 2022 to April 2023. This district has been selected since quarantine was imposed at all nodes along the pig value chain in all six sub-counties in the districts such as Moyo Town Council (MTC), Moyo Sub-County (MSC), Metu, Lefori, Laropi and Difule.

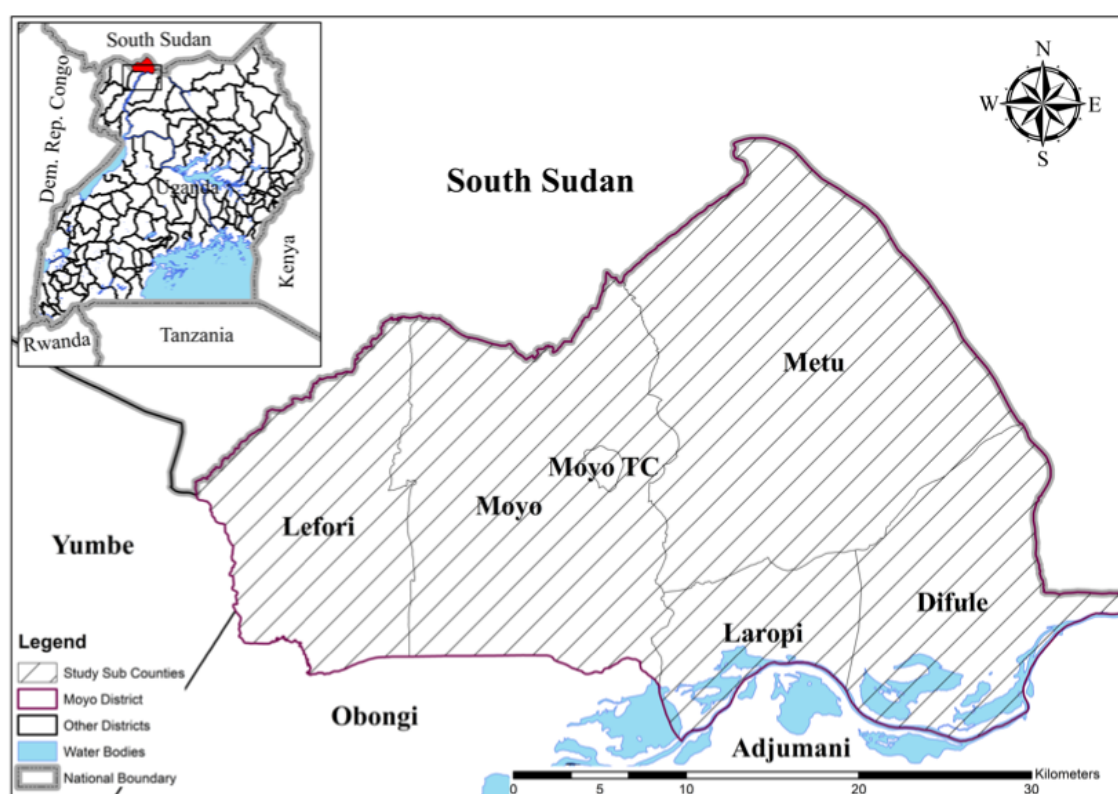


Figure 7.1: Maps of Uganda showing Moyo district. Maps created using ArcGIS version 10.8.0

In Moyo district, pigs and pig products in smallholder pig value chain are processed at relevant places which include 28 slaughter slabs distributed across all seven sub-counties, and 13 pork-joints located in four of the six sub-counties. The number of pigs and frequency of pig slaughter in 28 slaughter slabs varies across all seven sub-counties. MTC has only one slaughter slab which slaughters one pig every Sunday. MSC has one mini – abattoir which slaughters five to seven pigs daily, and five slaughter slabs functional during festive seasons (Christmas, and new

year celebrations), and public holidays (Ugandan Independence Day, Labor Day). In Metu sub-county, one slaughter slab handles one pig per day, and four slaughter slabs which are active in festive seasons and public holidays. Laropi and Lefori sub-counties have four and three slaughter slabs, respectively which handle pigs during the festive season and public holidays, and both sub-counties have one slaughter slab handling a pig weekly. Dufile sub-county has four slaughter slabs, handling pigs on public holidays and festive seasons only.

Of the 13 pork-joints in the district, MTC has eight pork-joints which operate daily, and Metu sub-county has one pork-joint operating daily and more two that are active during festive seasons and public holidays. Other sub-counties such as Laropi and Lefori each have one pork-joint operating weekly; these also operate on public holidays and festive seasons. Finally, MSC and Dufile subcounties have no pork-joints, with pork consumers accessing roasted pork from pork joints in nearby sub-counties, and raw pork from slaughter slabs during public holidays and festive seasons.

7.2.2 Overview of participatory system dynamics modelling and group model building

The study applied system dynamics (SD) modeling to address the various impacts of livestock diseases. System dynamics models are a means by which to analyze the behavior of complex systems and are rooted mathematically through a set of nonlinear differential equations that characterize these relationships. However, from a coding perspective, SD models represent and distill this complexity in a graphical framework, enhancing its ability to be used in multidisciplinary settings (Rich et al., 2011). An additional advantage of SD is in its ability to jointly model disease dynamics and evolution alongside production and behavioral dynamics within the value chain, which are more difficult or impossible to model in other meso-level platforms such as social accounting matrices or multimarket, partial equilibrium models. SD models have been previously used in a variety of livestock value chain studies, integrating production, economic, epidemiological and household characteristics to conduct scenario analysis and impact assessment (Rich et al., 2009; Rich et al., 2011; Hamza, Rich, & Wheat, 2014; Naziri et al., 2015). In addition, there have been previous studies using such techniques to address the economic impact of biosecurity interventions in ASF control more specifically (Ouma et al., 2018; Berends et al., 2021a). These studies implemented biosecurity at farm level.

Our SD modelling used a data collection and participatory model building technique called group model building (GMB) as a means of involving stakeholders in the conceptualization

and development of model structures, which in turn can be transformed into an operational quantitative SD framework capable of testing the suggested different scenarios focusing on interventions or policy implementation (Hovmand, 2014; Vennix et al., 1996). GMB is relevant when diverse types of stakeholders are involved, when many alternative interventions exist, and when it is difficult for stakeholders to understand individually the possible consequences of a collective decision made within a complex system (Vennix, 1996). It is also particularly appropriate in data-constrained environments, and the involvement of different stakeholders in the modeling process improves the internal validity of both structure and parameters. The outcome of a GMB process includes building of the model, awareness promotion, and motivation of participating community members and other stakeholders to reach consensus in decision-making processes concerning their community, thus increasing their commitment to equally own the results or outcomes (Cornwall & Jewkes, 1995; Andersen & Richardson, 1997; Hovmand, 2014). A number of recent studies have applied GMB in the context of livestock. Lie et al., (2016); Lie et al., (2017) applied GMB to develop dairy sector models in Nicaragua. In the context of the pork sector, Berends et al. (2021b) developed a pig sector model using GMB techniques that included a module on ASF-induced disease shocks for the pig value chain in southern Myanmar, while Ouma et al., (2018) applied GMB to assess the effects of farm biosecurity investment on the profit margins of different value chain actors in Uganda

The GMB process requires the selection of key stakeholders with the knowledge of the system in question and sufficient diversity in perspectives to address its complexity along a range of factors. In Moyo, the selected participants involved in the GMB sessions included core participants within pig value chain, a reference group of experts, and a group of facilitators to manage the model building process. A total of 14 core participants comprised of small-scale and medium-scale pig farmers (n=5), pig traders (n=3), pork retailers (n=3) and pork consumers (n=3) were purposively chosen by DVO based on their knowledge of the pig value chain and past experiences with ASF. The inclusion of women (over 50%) in our group highlights the important roles that women perform in the value chain (Rubin, Deborah, and Manfre, 2014). The facilitation team consisted of two facilitators, two modelers, and one notetaker, all with specific roles and responsibilities used to facilitate the participatory model building process and discussion. A reference group was convened, comprised of five technical experts (DVO of Moyo, District planner of Moyo, District revenue officer of Moyo, a university agricultural economist, and an inspector of disease regulations in charge of West-Nile subregion of Uganda) and used to complement and validate or refine GMB outputs from

stakeholder discussions. Their role served as a triangulation role to ensure the internal validity of information collected from value chain stakeholders and to address any gaps from the participatory modelling process.

7.2.3 Data collection and model building

The data collection process involved two half days of participatory workshops following the schedules in the program as in Appendix 7.1.

Day one (8:30am – 1:00pm): The GMB process started with a preliminary session addressing the workshop goals (improvement on ASF control to increase pig production and livelihood income of farmers and other value chain actors). Participants were introduced by their role in the value chain. Participants who could not read or write very well were given guidance and support when asked to write something down. A “hopes and fears” exercise was used to gauge participant expectations through discussing what they feel as key issues that would come up during the two-day meeting. Using two cards of different colors, every participant wrote one hope and one fear on the cards provided. These cards were pinned on the wall and clustered into similar groups to provide a set of key issues that could help to define the key problems as perceived by the stakeholder group and establish model boundaries during the workshop as described by Rich et al., (2022).

In the second session on day one, system dynamics concepts were introduced to participants using a simple illustration that described key building blocks and SD vocabulary such as stocks, flows, converters and feedback loops. Figure 7.2 gives an example of such building blocks using Vensim (version 10.0), a common SD software, and portrays a stock and flow diagram of pig population. In this case, with the help of the diagram, participants were exposed to the terms used in SD such as stocks (pig population), flows (being born or dying), converters (birth rate or death rate), connectors, and feedback loops. Both types of feedback loops are present in this diagram, with reinforcing loops (R) highlighting an exponential growth (or decay) process, while balancing loops (B) indicating convergence to some target or equilibrium. In figure 2, pig growth is represented as a reinforcing loop (as pig population grows, the more pigs are born, which increases the population further), while pig deaths are represented as a balancing loop (as pig population grows, the more pigs die, which reduces the number of pigs).

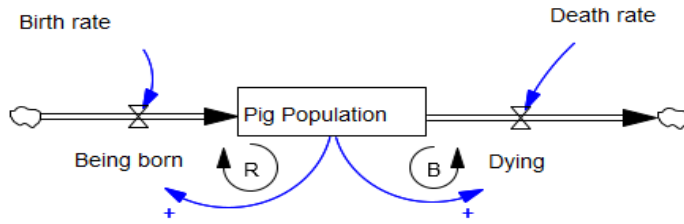


Figure 7.2: SD illustration diagram

The third session on day one involved the elicitation of key variables to trigger and gauge participant knowledge of ASF control. Adapting the approach of Lie et al. (2017), every participant wrote on manilla card one problem associated with failure to control ASF disease in Moyo and other parts of Uganda. Fourteen problems that were identified (one per participant) were pinned on the wall. Every participant then voted on the two top problems. The highest ranked problem was “lack of knowledge” followed by “poverty”. A causes and consequence map, which highlights the drivers and implications of a given problem, was developed for the two priority problems in small groups. We defined reference modes illustration using graphs to show behaviours of selected consequences such as pig population and marketing trend over time, with and without ASF control intervention during outbreak. This sketch of behaviour provided a baseline of what participants might expect a model to produce.

Day two (8:30am – 1:00pm): On the second day, stakeholders modified two sets of pre-packaged questions called “question-scripts” (informed by the baseline study, see (Aliro et al., 2023)) by incorporating other relevant questions. The modified question-scripts were used to guide stakeholders generate relevant data during group discussions. The first set of scripts called “farmers question scripts” included on-farm information such as production costs, pig breeding and growth rates, available pig categories, pig and pork prices, pig sales rates, pig health management costs, and pig death rates (Appendix 7.2). The second set of scripts called “traders question scripts” included other information along the value chain such as traders production costs, pig cost, pork prices, rates of pig purchase and pork sales (Appendix 7.3).

Stakeholders were then split into two groups to discuss and come to consensus on parameter values to be used for simulation of the model. Group-1 comprised of seven members (farmers=5, trader=1 and pork-consumer=1) used “farmer parameters scripts”. Group 2 composed of seven members (traders=2, pork-retailers=3 and pork-consumers=2) used “trader parameter scripts. The purpose of group heterogeneity was to utilize “seller – buyer”

relationships to obtain data along dimensions in which they share in common such as the cost or price of pigs and pork, and biosecurity requirement. Participants provided data on the associated costs of production and biosecurity requirements in the value chain, and revenues across all the value chain nodes. Furthermore, they also provided detailed information on various technical parameters such pig birth rates, pig growth at different ages, sales and purchases, and also change in prices over time (before and during ASF outbreak, during and after quarantine imposition was lifted), and delays in production due to biological and decision-making processes. Participants reconvened after group discussion, and every group presented parameters (values) they generated in the scripts for further discussion. Modelers received the agreed parameters to run the model.

Reference Group Meeting: GMB meetings were supplemented by interacting with reference group members through group and individual meetings, and *ad hoc* interaction (phone calls) as recommended by Lie et al., (2017). In the morning of day three, a meeting with Moyo district officials (district veterinary officer, district planner, and district revenue officer) focused specifically on data and a topic that were difficult for the GMB participants to provide details. This data included the number of households keeping pigs, the number of pig traders, the number of slaughter slabs and pork joints, total pig population, pig and pig product marketing dynamics including international cross border trade, an overview of the past ASF situation, and records of relevant secondary data. The discussion with Moyo district officials also provided background information on the roles played by key district leaders during quarantine implementation.

Separately, a meeting was held with a Gulu University agricultural economist to discuss key economic aspects regarding the pig value chain, including farm production costs, revenue bases, and expected profit margins. Discussions on the influence of consumer demand and supply quantity on prices of agricultural products. An additional phone conversation was also made with an inspector of disease regulations in charge of the West-Nile subregion. This discussion covered the ASF situation in West-Nile, government recommended periods of quarantine imposition, and the movement of pigs and products within the subregion and across international borders with South Sudan and the Democratic Republic of Congo (DRC).

7.2.4 Description of study model structure

On the herd side, animals are separated into different age cohorts (piglets, growers, and adult pigs). Their evolution between states depends on the length of time spent in a given state, with exits from each stock possible due to mortality or sales, see Figures 7.3 and 7.4.

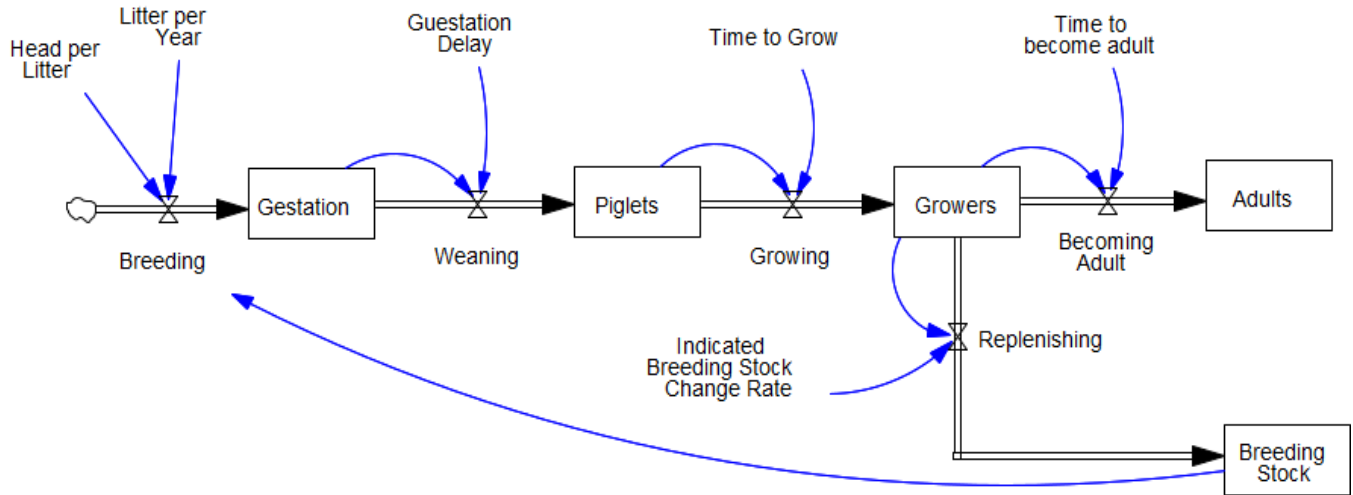


Figure 7.3: Module structure for pig production side

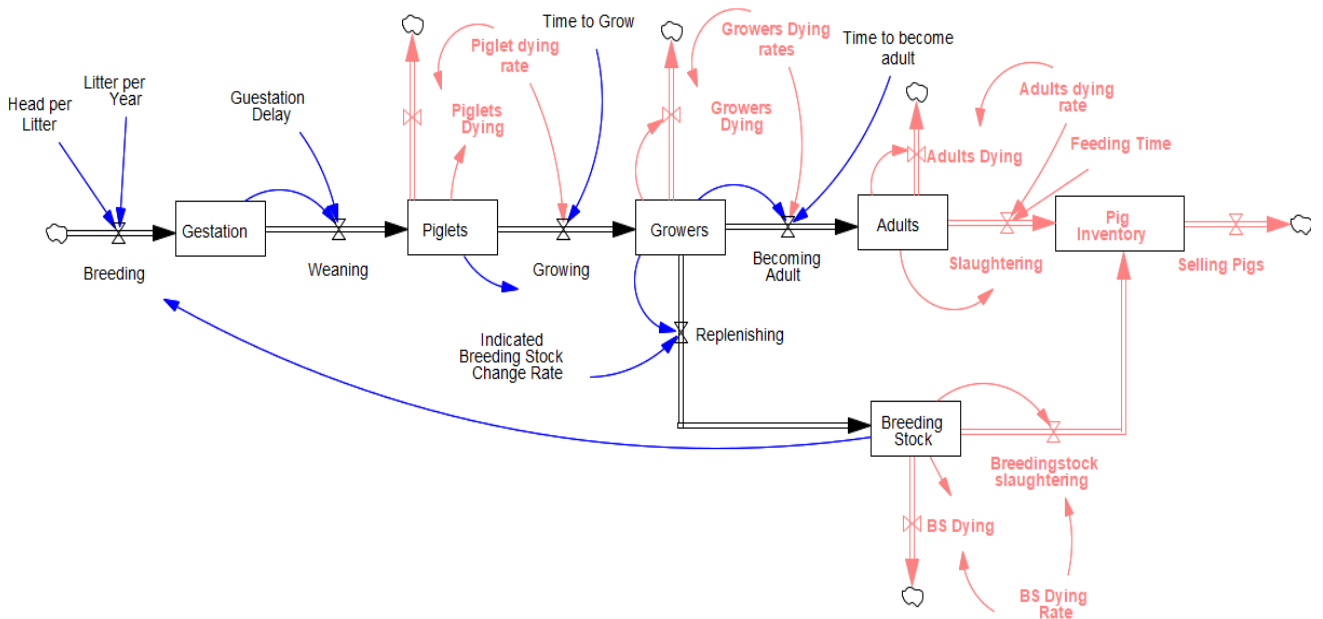


Figure 7.4: Module structure (sections in red) shows what depletes pig population

Demand is specified as a simple double-log equation relating pig quantity to its price. SD models of supply and demand typically relate equilibrium through the presence of inventories and the balance between actual inventories and desired inventories, see Figure 7.5. When actual

inventories exceed desired inventories, this puts pressure on producers to reduce stock, causing prices to fall. By contrast, when desired inventories exceed actual inventories, this bids up prices in an effort to obtain more supply. In the model, price signals (with a delay) further give signals to farmer whether to invest in new capacity to raise or reduce future pig production, based on the profitability of pigs related to their costs. Costs in the model include feed costs, biosecurity costs, and other costs obtained through the participatory sessions. Downstream, the dynamics of traders are modelled to capture their revenue from pork sales, which varies according to pork type (raw and or roasted). The total production cost of traders included business transactions cost, and other costs such as biosecurity.

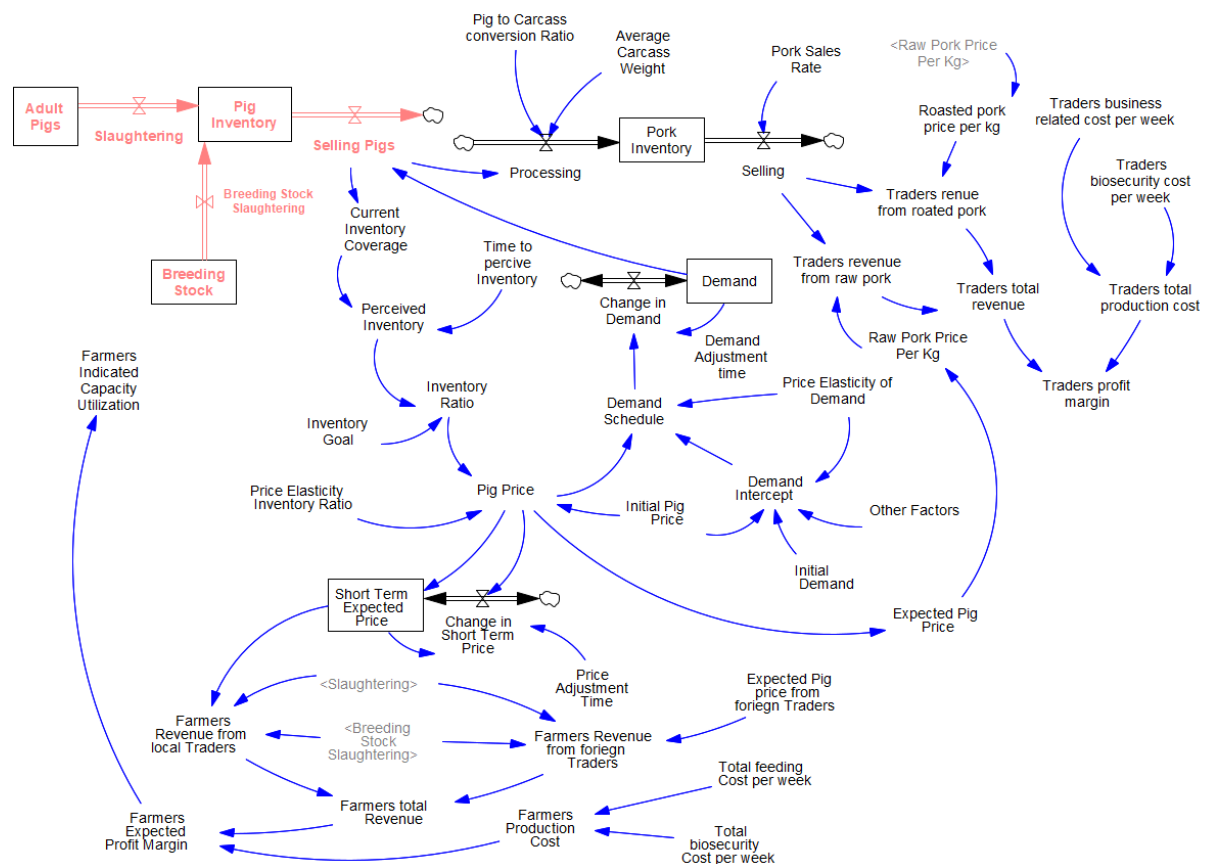


Figure 7.5: Module structure for marketing side

ASF affects the dynamics of the model in a number of ways, see Figure 7.6. First, ASF-induced mortality is modelled as the exit of pigs from each of the age cohort stocks based on the death rate associated with ASF per week. Second, ASF can (in some cases) cause changes in demand due to consumer perceptions of the disease. Finally, in an effort to stop the spread of ASF, policymakers will impose quarantines and movement controls which shut markets, causing farmers to hold stock longer than normal and resulting in pork shortages in the market for consumers. Scenarios that address these dynamics are presented in detail in the next section.

Table 7.1 Conceptual framework for assessing ASF impact: Quarantine scenarios

Scenario (S)	Rate of Pigs death per week	Duration of ASF outbreak and quarantine	Fraction of market closure	Changes of consumers demand
S1	Baseline			
S2	0.01	30 weeks	0%	0%
S3	0.01	30 weeks	30%	0%
S4	0.01	30 weeks	50%	0%
S5	0.01	30 weeks	30%	-30%
S6	0.01	30 weeks	50%	-50%

The study also considered a second set of simulations summarized in table 7.2. In these scenarios, we modelled the impacts of increasing biosecurity cost such as construction of fences and isolation units, and use of chemicals as an additional means to reduce ASF mortality rate and increase productivity. These two additional scenarios are labelled as S7, which is similar to scenario S5 but in which we assume a lower biosecurity-aided death rate of 0.0025 (25% of 0.01) and an increase in biosecurity investment costs by 30%, and S8, which is similar to scenario 6 but in which there is a further 50% reduction in the death rate from 0.01 to 0.005 (50% of 0.01) that results from a 50% increase in biosecurity investment costs.

Table 7.2 Conceptual framework for assessing ASF impact: Quarantine, demand and Biosecurity scenarios

Scenario (S)	Rate of Pigs death per week	Duration of ASF outbreak and quarantine	Fraction of market closure	Changes in consumers demand	Increase farmers' biosecurity cost
S5	0.01	30 weeks	30%	-30%	0%
S6	0.01	30 weeks	50%	-50%	0%
S7	0.0025	30 weeks	30%	-30%	30%
S8	0.005	30 weeks	50%	-50%	50%

7.3 Results

7.3.1: Baseline data of pig slaughter volumes for retail in Moyo town council

Before presenting our model results, we first highlight data from secondary data associated with previous ASF outbreaks that guided our parameterization. Figure 7.7 provides data on the number of pigs slaughtered in 2022 and 2023 from MSC mini-abattoirs. The data highlights time periods in which quarantines were imposed – for 28 weeks, between 22WK41 and 23WK17 (where 22WK41=week 41 of year 2022 and 23WK17= week 17 of year 2023). The trade ban started from 15th October 2022 and ended on 26th April 2023. The data shows high

levels of pig slaughter volumes in festive periods such as in Christmas (23WK51), New Year's Eve (23WK52) and New Year's Day (22WK1). Other weeks with high pig slaughter volumes are during national and international public holidays such as Liberation Day (22WK4), Archbishop Luwum Day (22WK7), International Women's Day (22WK10), Easter (22WK16-17), Labor Day (22WK18 and 23WK18), Martyrs Day (22WK22 and 23WK22), Heroes Day (22WK23 and 23WK23), and Independence Day (22WK40 and 23WK40).

Based on average weekly slaughter volumes, the closure of the MSC mini-abattoir and all the other district slaughter slabs resulted in 1602 pigs and 44,144 kg of carcasses (average carcass weight was 27 per slaughtered pig) lost when pig slaughter was suspended during quarantine. Assuming exchange rates (1\$=3,700 Ugandan shillings) in 2022 and 2023, financially, the closure affected farmers (1,602 pigs @ \$100 per pig = \$160,200) less than traders (44,144kg @ \$4 per kg = \$176,576). This financial loss could have been exacerbated by the high number of pigs expected to be slaughtered in 2022 festive season and from four public holidays in 2023, all of which took place during the quarantine period. The weekly numbers and carcass weights of pigs slaughtered between 22WK17 and 23WK26 in 2022 before quarantine and between 23WK17 and 23WK26 in 2023 after quarantine, representing 10 weeks from April to June, show higher figures in 2023 (an average of 65 pigs and 1,800kg) compared to 2022 (an average of 40 pigs and 1,100kg). The buildup in the number of unsold pigs during quarantine, and actors actively involved in pig and pork businesses, resulted in trade in large numbers of pigs when the trade ban was lifted, thus leading to an increase of 63% in pig numbers and 64% in carcass weights of slaughtered pigs in the first 10 weeks after the trade ban was lifted.

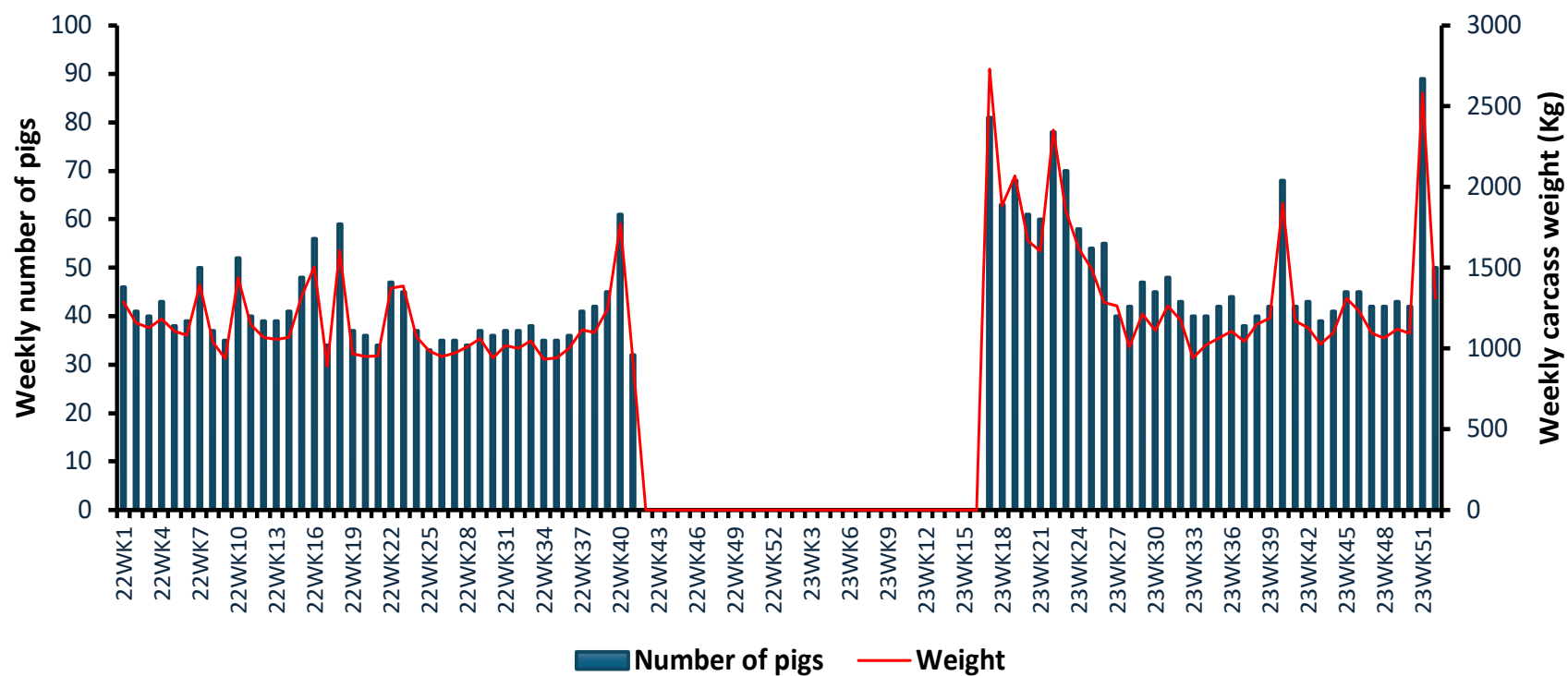


Figure 7.7: Pig slaughter volumes during 2022-2023, before and after quarantine imposition. 22WK denotes weeks in 2022; 23WK denotes weeks in 2023
Source: DVO's abattoir record

7.3.2 Preliminary Model Results

7.3.2.1 *Simulation results of quarantine scenarios during ASF outbreaks*

The results of from these scenarios are summarized in Figures 7.8a-g. In these figures, line S1 denotes the baseline as farmers transact pig business normally with local traders within West Nile and foreign traders from neighbouring country. Under S2 where no trade bans are imposed, an ASF outbreak causes an initial reduction in live pigs and pork quantities (Figures 7.8a-c). The quantities of adult pigs and pig inventory start falling from the beginning of the outbreak (i.e. in week 120), but the reduction in pork inventory quantities commences five weeks later (in week 125) given the lag in selling pigs to the market. As the quantities of pig and pork inventories fall, the prices of live pigs and pork show sharp increases during outbreak (S2, in Figures 7.8d and e) peaking in week 145 for both live pigs and pork. Trader and farmer profit margins show fluctuations during S2. Relative to S1, trader profit margins initially rise by 21% in week 134 then slowly drop as shown in Figure 7.8f. Similarly, farmer profit margins steadily fall during the first few weeks of the outbreak before rising above S1 by 14% in week 150, Figure 7.8g.

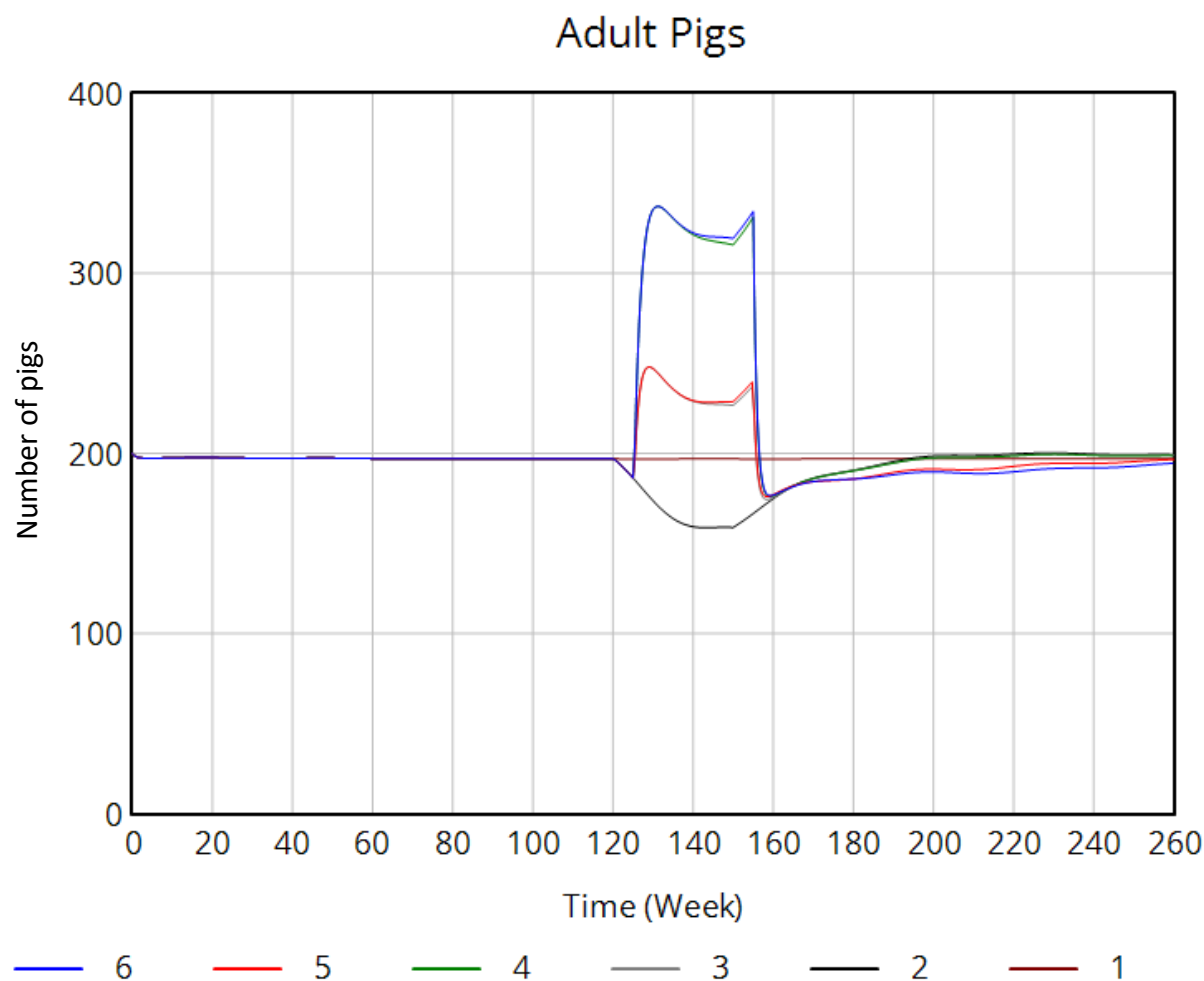
Under S3 and S4, with different scenarios of market closures and no change in consumer demand (Figure 7.8a-b), we observe the number of adult pigs increases by 15% in S3 (week 140) and by 60% in S4 (week 150), as pigs are no longer being sold to all markets due to market closures and remain on farm. Sales bans of live pigs and pork due to market closures (S3 and S4) cause a rise in prices per pig and per kg of pork (Figures 7.8d and e), with peak curve heights slightly lower than S2. The fluctuation in traders profit margin in S3 is relatively the same as for S2. However, trader profit margins in S4 initially rise by 7% in week 140 then drop by 4% in week 154 as shown in Figure 7.8f. Similarly, farmer profit margins drop by 7% in week 134 and 29% in week 134 under S3 and S4 respectively, before rising above the level of S1 by 11% in week 150 in S3 and by 7% in week 150 under S4 as shown in Figure 7.8g.

Combining different levels of market closures and reducing consumers demand (S5 and S6), results in an increase in the number of adult pigs in a similar manner to when there was no change in consumers demand (Figure 7.8a: by 15% in both S3 and S5; by 60% in both S4 and S6). With

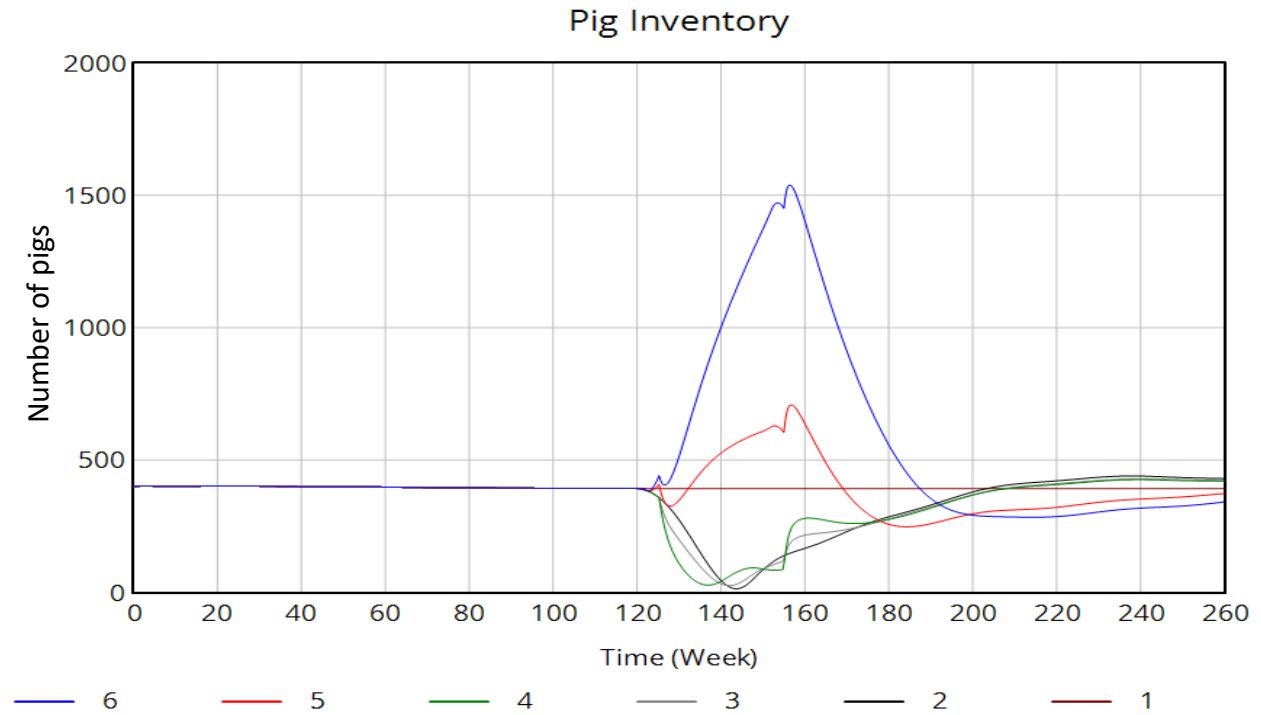
the reduction in consumer demand, pig inventories on farm rise, while trade bans further dampen inventories of pork. Combined, this has the effect of reducing the pig price by 20% in S5 (week 140) and 40% in S6 (week 150) see Figure 7.8d and pork price by 32% in S5 and 45% in S6, see Figure 7.8e. The low sales and prices for both pigs and pork marginally decreases the expected profit margin for traders' expected profit by 7% in S5 in week 130 and 29% in S6 in week 130 as shown in Figure 8g, and for farmers by 10% and 15% in S5 and S6 respectively in week 130, see Figure 7.8g. Feeding the increasing pig herd size in the farm increases farmer operational costs, which in turn further lowers farmer profit margins by 18% in S5 and 25% in S6 seen in week 155.

Figure 7.8: Results from the SD model of ASF control intervention using scenarios of quarantine and consumers demand for pork.

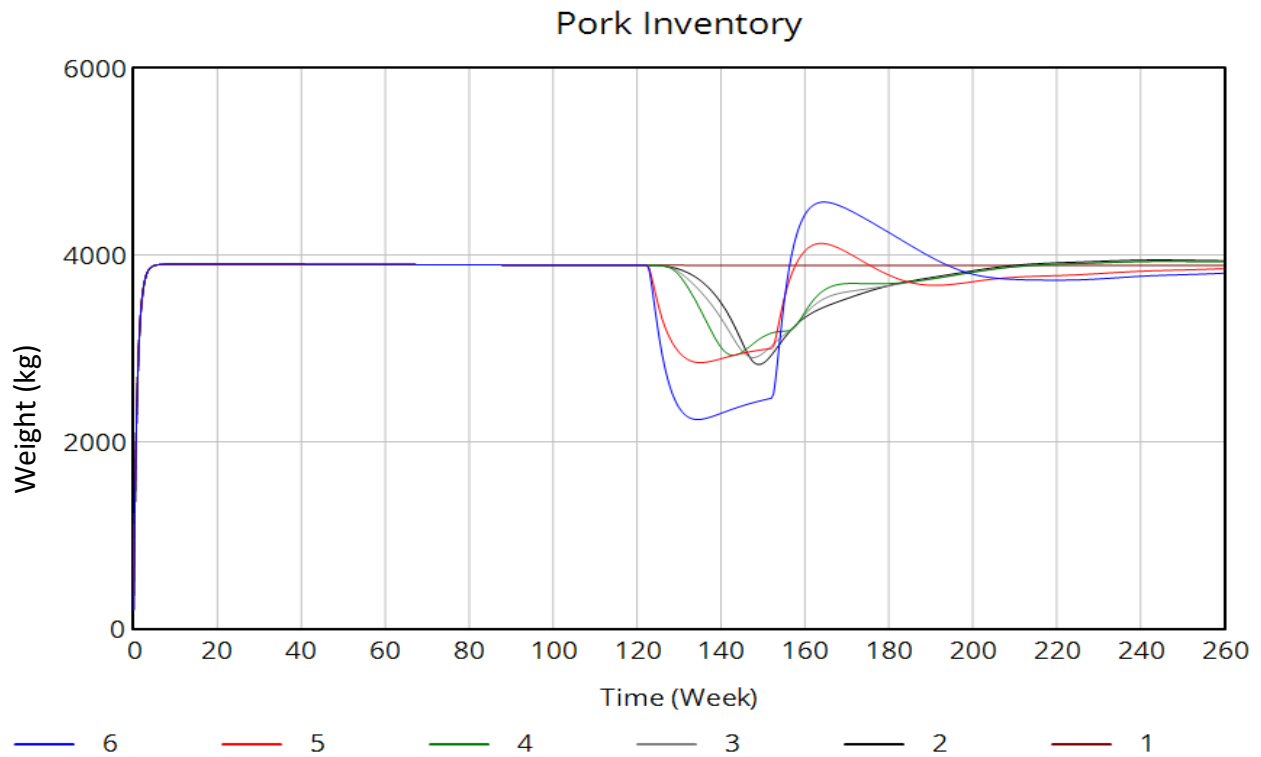
(a) Adult pig dynamics



(b) Marketable pigs allocated for sale



(c) Pork available for sales



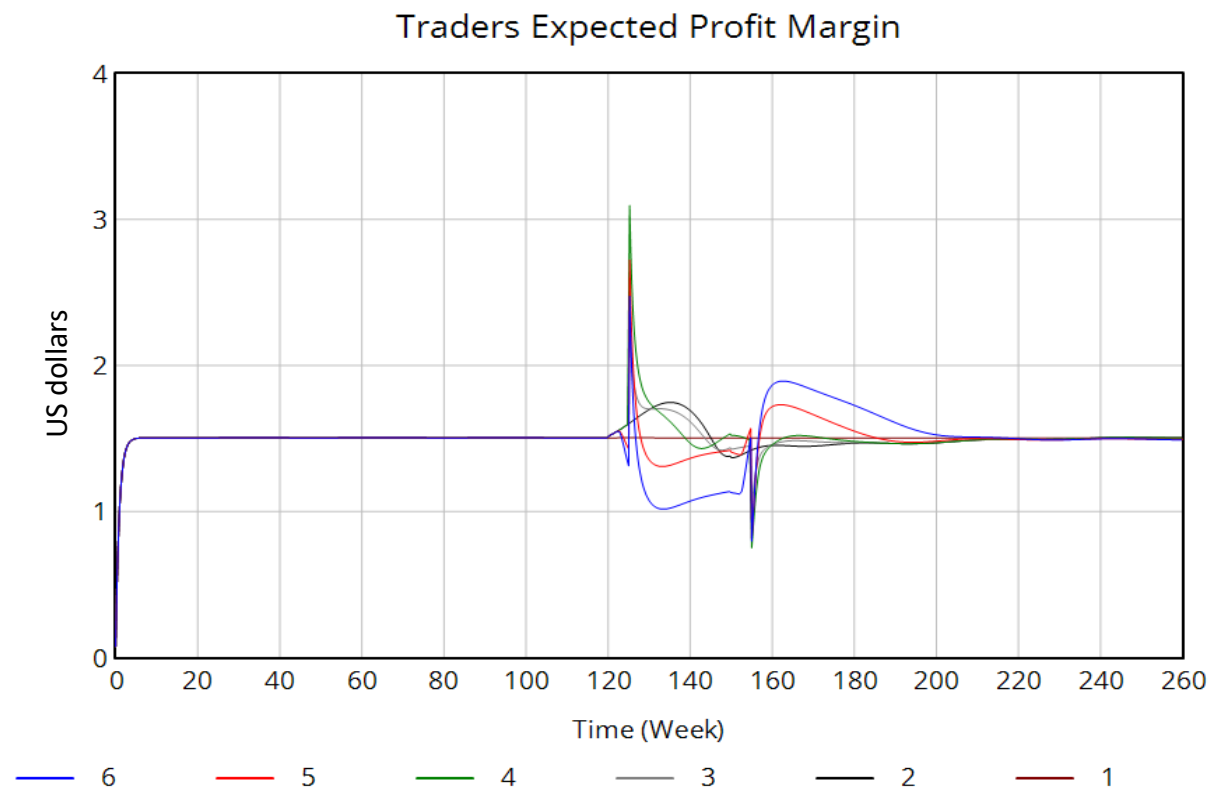
(d) Expected price of pigs



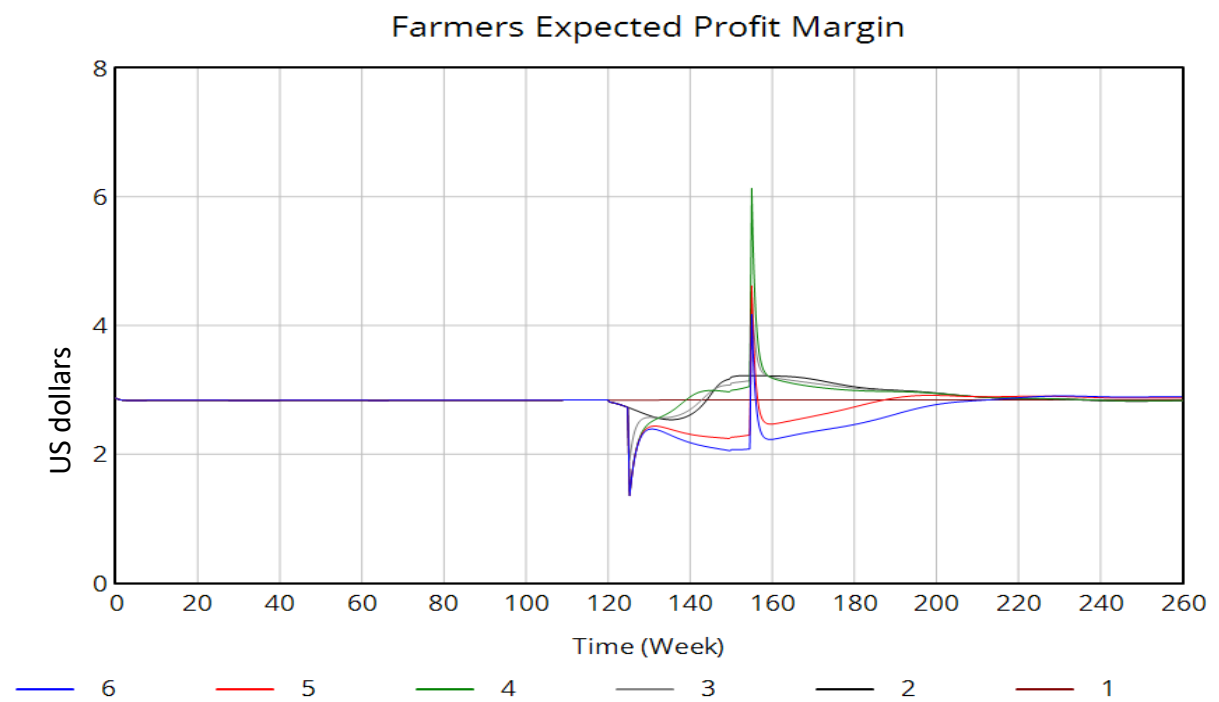
(e) Expected pork price



(f) Traders expected profit margin



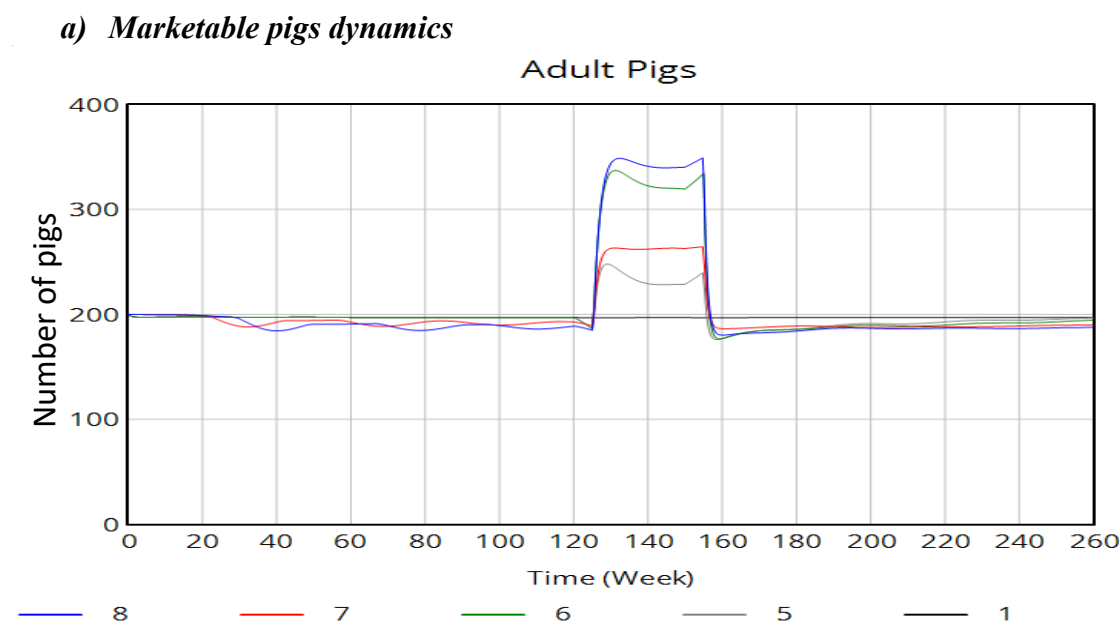
(g) Farmers expected profit margin



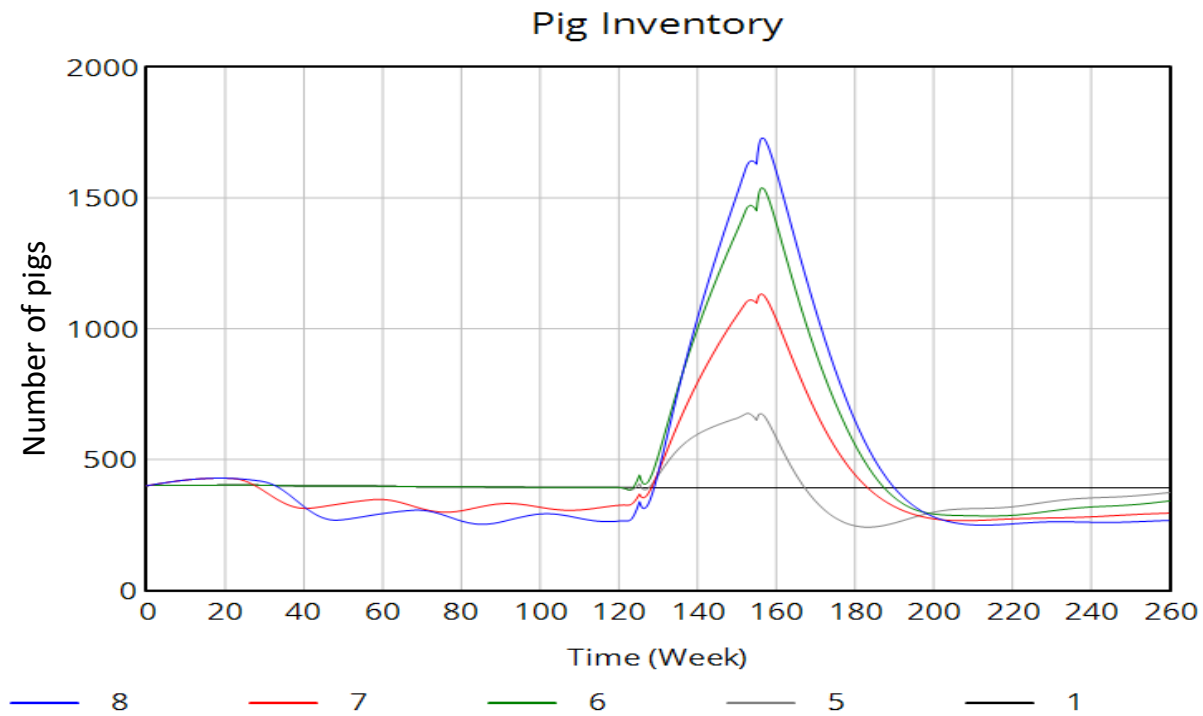
7.3.2.2: Set II - Quarantine combine with improvement on farm biosecurity

The results of increasing farm biosecurity costs (S7 and S8) relative to the baseline (S1) and varying levels of market closures (S5 and S6) are presented in Figures 7.9a-d. These four figures represent changes in the number of adult pigs, pig inventories, pig prices, and farmer expected profit margins. The results of increasing farm biosecurity costs by 30% in S7 and 50% in S8 relative to the baseline (S1) and varying levels of market closures as in S5 and S6 are presented in Figures 7.9a-d. These four figures represent changes in the number of adult pigs, pig inventories, pig prices, and farmer expected profit margins. In all scenarios (S5-8 in Figure 7.9a), the number of adult pigs increased sharply from week 125 to 130 and remained high at certain level (depending on specific scenario) until end of the trade ban in week 155. The number of adult pigs in S7 and S8 and that of pig inventories are higher than their corresponding levels in S5 and S6 respectively throughout the outbreak. In Figure 7.9c, pig prices decline in all scenarios from week 125 until end of trade ban in week 155, driven by the reduction in consumer demand, with the sharpest falls occurring under S6 and S8. Farmer margins stay considerably depressed in these scenarios, though rebounding sharply after week 160 as prices begin to recover rapidly (figure 7.9d).

Figure 7.9 Results from the SD model portraying the effects of biosecurity investment on the number of mature pigs and farmers profit margins



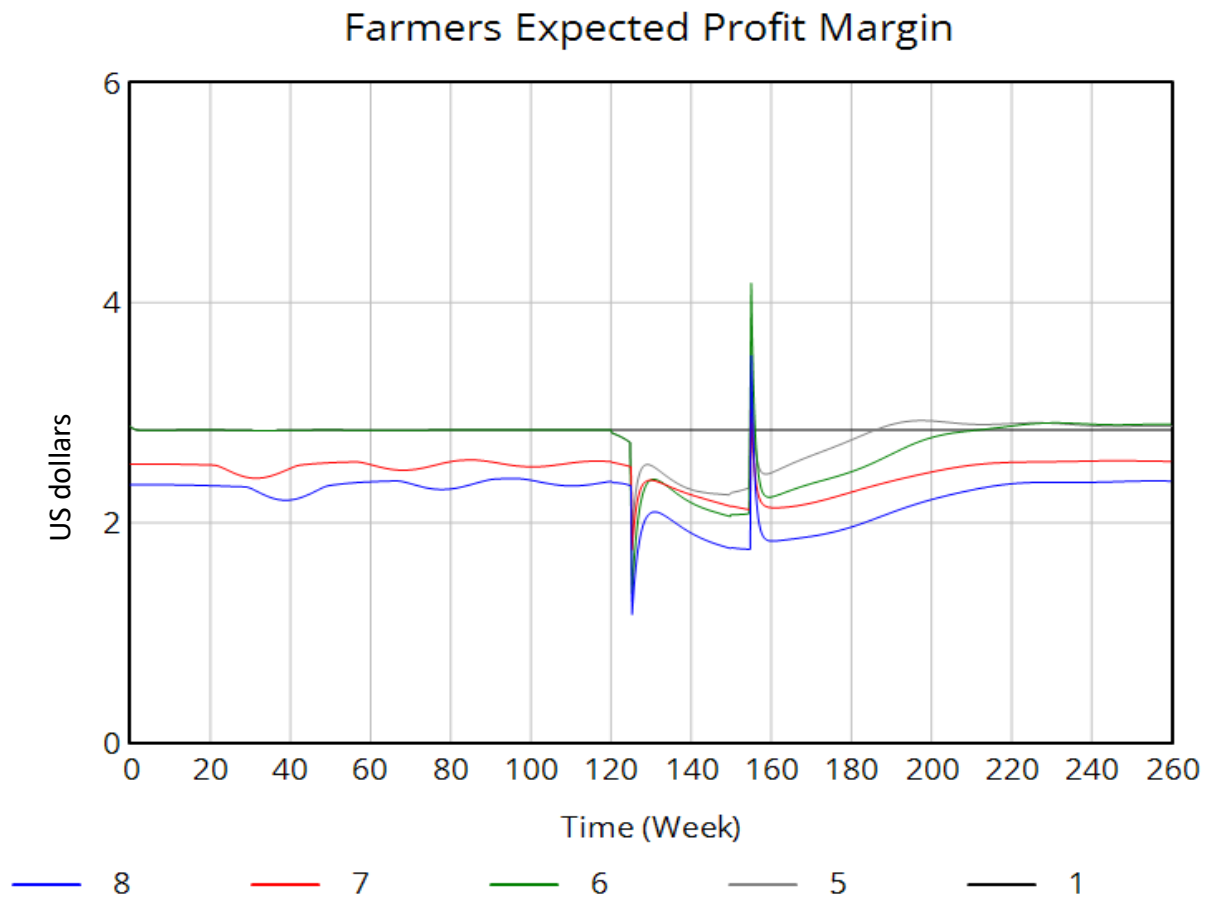
b) Marketable pigs allocated for sales



c) Pig price changes



d) *Farmers Profit Margin*



7.4 Discussion

The modelling of two ASF control interventions, namely the application of quarantine or trade ban policy, and a combination of this policy with enhanced biosecurity investment provided insights into various production and market dynamics that arise and inform directions for policy and outreach. Four new areas that emerged from our study, and their respective implications in terms of ASF control in Uganda are presented below;

1. Trade bans have the effect of increasing pig herd size on farm, as market closures reduce the number of pigs leaving the farm and subsequently lower pig and pork movement in the community.

2. Low pork inventory observed throughout the trade ban period whether consumers demand changed or not.
3. Farmer and trader margins stay depressed throughout the outbreak when consumer demand falls, driven by lower prices for pigs and pork, while unchanged demand leads to different impacts for farmers and traders. In the case of trader margins with no demand shock, after an initial spike these remain elevated but falling, with higher prices offsetting the impacts of lower sales. By contrast, for farmer margins with no demand shock, these are initial below baseline levels but as prices rise and the number of adult pigs falls slightly due to mortality on farm, these rise to a steady level.
4. Enhanced biosecurity investment resulted in further increase in herd size and reduction in farmers profit margins. Although the additional increase in herd size makes biosecurity enhancement superior to trade ban in protecting pig population or epidemiologically beneficial, given the further drop in profit margin, farmers are likely to prefer trade ban policy alone which increases herd size too without incurring additional cost.

In scenarios in which consumer demand does not change, the number of adult pigs held on farm rises, as trade bans prevent their sales, causing a decline in pig and pork inventories and a corresponding spike in prices. These changes take place with a lag as the effects of trade bans take time to register. When consumer demand falls, this causes a shift back in the demand curve which boosts pig inventories and cause prices to fall. Adding trade bans with enhanced farm biosecurity when consumers demand declines (S7 and S8) further increases both the number of adult pigs and pig inventory due to reduced pig death rates. Farmers are holding so many pigs more than the market is demanding, again causing prices to fall further. In addition, our findings show that in scenarios S7 and S8 further reduce farmer profit margins due to increased production cost.

Our findings shows that trade ban scenarios applied alone increased the profit margins of traders (21%) earlier in week 134 and late for farmers (11%) in week 150 due to changes in pig herd size, inventory and prices. The high traders' profit margin observed at the initial stage of trade ban was a "forwarded-profit" gained during outbreak, before quarantine imposition, when traders bought several pigs cheaply (farmers adult pigs and pig inventory dropped). Studies reported that during ASF outbreak, farmers sell pigs cheaply out of panic and deleting pig herd (Nantima et al., 2015; Dione et al., 2016; Dione et al., 2017; Ouma et al., 2018; Berends et al., 2021). Traders were unable

to sustain these gains for long, as their profit margin starts declining gradually as farmers pig inventory falls and the pig price increases sharply. Farmers' low pig supply to the market (pig inventory dropped) due to trade restriction could have maintained the initially low farmers profit margin which started during outbreak, before trade ban imposition. The low pig supply combined with its high selling price (exacerbated by international cross-border trade), and the prolonged trade ban period were possibly enough to cumulatively increase farmers' profit margin observed in the end.

In trade ban scenarios when human behaviours remain unchanged (S3 and S4), the increased profit margins seen earlier (first five weeks into trade ban period) among traders but late (last five weeks before lifting trade ban) among farmers were associated with trade dynamics of pigs and pork inventories/prices in the market. The fluctuations in trader profit margins which are marginally the same as in the outbreak scenario (S2), starts increasing gradually from a higher value point as it follows the trend in S2 and reaches a peak in week 135. This fluctuation is influenced by changes in pigs and pork inventories and prices, while the high prices all observed in trade ban scenarios are marginally similar with the one in S2. Despite these short-lived peaks in prices, traders were unable to sustain gain in profits for long, as their profit margin starts declining gradually and crosses the baseline point in week 150 as farmers pig inventory falls and the pig price increases sharply.

Fluctuations in farmer profit margins in trade ban scenarios are also marginally similar with what is observed in S2, in this case, in terms of changes in the number of adult pigs, pig inventories, and pig prices. Farmer profit margins dropped gradually to their lowest point in week 130, and subsequently increases gradually until when it crosses the baseline point in week 150, and it continues increasing gradually until it week 155.

Under trade ban scenarios when consumers demand falls (S5 and S6), trader profit margins decrease sharply to their lowest level (below baseline value) observed in week 130 due to a continuous drop in pork inventory combined with a reduced pork price. Then traders profit margins rises slightly (but below baseline) from week 130 to end of trade ban in week 155. Farmers profit margin fluctuated below baseline during trade ban when consumers demand falls. Initial small drops in farmer profit margins in week 130 were due to increased pig inventory and reduced pig

price as trade restrictions greatly lowered pig sales. The second stage of gradual decline in farmers profit which occurred from week 130 until week 155 was associated with incurred cost of feeding the increasing pig herd size as sales of marketable pigs was delayed.

Combining trade bans with enhanced farm biosecurity when consumers demand falls (S7 and S8) and comparing with S5 and S6 when there is no enhanced biosecurity, the result shows that farmer profit margins fluctuate below the baseline profit in all four scenarios. The initially drop in farmers profit margins in week 130 in S7 and S8 is more than in S5 and S6, respectively, were linked to further increases in number of adult pigs and pig inventories given lower mortality rates in S7 and S8. As farmers hold more pigs than the market demands, this causes prices to fall further. The further gradual decrease in farmers profit margins from week 130 until end of trade ban (week 155) in S7 and S8 more than in S5 and S6 respectively were due to increased production cost as a result of added biosecurity costs and the cost of feeding a large herd size arising from reduced mortality and very low sales.

Our study and other previous studies (Ouma et al., 2018; Berends et al., 2021) applied GMB approach to estimate the distributional impacts of ASF control interventions along the smallholder pig value chain. However, our participatory process was much more thorough and empowering of stakeholders and enabled us to capture information at a much more granular level, not done in any previous studies. We recommend future research directly incorporate epidemiological models such as the Susceptible-Infectious-Recovered (SIR) model to analyze the impacts of different outbreaks and their feedbacks from production and marketing on the evolution of outbreaks themselves.

In conclusion, reducing the pig mortality rates through enhanced biosecurity can improve outcomes from ASF outbreaks but there is a trade-off with greater incurred costs. Further research that integrates epidemiological models directly within an SD framework will provide greater granularity on the impacts of different outbreaks and their feedbacks from production and marketing on the evolution of outbreaks themselves.

CHAPTER EIGHT: GENERAL DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS

8.1 Introduction

Global concerns regarding ASF management have grown over years since first confirmation of the virus in 1921 in East Africa and as the occurrence have expanded to other continents outside Africa (Montgomery, 1921; Penrith et al., 2024). The wide global spread of ASF has greatly affected livelihoods in low-income countries such as Uganda. This wide distribution has revealed exiting challenges in the current prevention and control methods being used. With no safe and effective vaccine, mechanism that can facilitate involvement of key stakeholders in understanding the implementation of biosecurity measure along the complex pig value chains, is important for ASF control.

The overall objective of this study was to assess stakeholders' perception of existing ASF control measures that are feasible and affordable at local settings, assess adherence to implementation of biosecurity protocols and associated cost of control in pig value chain. The discussed results that answered specific research questions linked to the specific objectives are presented in the previous chapters. Chapter six presents a general discussion of selected research findings derived from each of research objectives and research questions presented in Chapter one. It does so by revisiting the study objectives and research questions, presenting a general discussion, presenting the empirical and practical contributions of this study, and providing suggestions for future studies.

8.2 Research objectives revisited

8.2.1 Stakeholders' perception of ASF control methods in smallholder pig value chain (O1)

There are several basic biosecurity measures recommended for prevention and control of ASF in smallholder pig production settings (Montgomery, 1921; Penrith et al, 2021b; Kim et al., 2022). In O1 of this study, the perceived existing biosecurity measures, summarized in two categories as;

“ASF biosecurity measures perceived as positive and most effective”, and “local knowledge ASF transmission” are all within general biosecurity measures related to good husbandry practices. Two key biosecurity measures perceived as mostly positive and effective are simple measures such as total confinement of pigs in pigsty enclosed with a fence to avoid roaming pigs coming in contact with ASFV contaminated materials or infective tissues and sick pigs in outside environment and informing neighboring farmers and other stakeholders about ASF outbreak in the area. Biosecurity measures known to community are effective in prevention and control of ASF, but implementation reported in this study is partially hindered by; cost of required materials, cultural and traditional factors, priority given to livelihoods, and inadequate provision of veterinary services.

8.2.2 Risk factors associated with introduction and spread of ASF in a large-scale commercial farm (O2)

The level of farm biosecurity in Uganda is generally low (Chenais et al., 2017a; Dione et al., 2018; Ekakoro et al., 2023). Large-scale, commercial farmers might have higher capacity than small-scale farmers to invest in biosecurity but lacks adherence to implementation. Having the biosecurity “hardware” such as buildings, fence, equipment, tools, and others in place, might however not be enough to prevent ASF introduction and spread, if biosecurity “software” implementation on daily routine are not complied with (Chenais et al., 2019b). Investigation of ASF outbreak in a medium-scale pig farm in Uganda revealed biosecurity breaches (Chenais et al., 2017a). The O2 of this study described sources of ASFV introduction into and spread within a large-scale commercial farm. This study identified several possible routes of ASFV introduction in IMF, which could be the feeds and other contaminated fomites from vehicles. Following a successful ASF viral entry into biosecurity level-I, one of the identified several potential access points into biosecurity level-II could be through activities in Ramp-I where disinfection doesn’t occur despite being a point for offloading pigs bought from farmers for restocking purpose. Index cases were reported in Dry Sow Houses during both 2021 and 2022 ASF outbreak waves. Pig to pig body contact via open metallic rails used for partitioning could have allowed spread of ASFV within the houses. Other sources of ASFV spread within and across houses were likely through movements of pigs, and contaminated fomites such as equipment and workers’ protective gears. Inadequate implementation of biosecurity measures is a big challenge in all small-scale with limited capacity

(Dione et al., 2016a), medium-scale (Chenais et al., 2017a) and large-scale commercial farms that have better capacities for implementation.

8.2.3 Actions taken by different stakeholders and the perceived economic impact during quarantine (O3)

Perceived loss of pig farmers' income is associated with cost of investing in biosecurity (Dione et al., 2020). Farmers willingness to take part in preventive action, is hindered by cost of implementing biosecurity measures, which is perceived as non-beneficial (Dione et al., 2017b; Mutua & Dione, 2021; Ekakoro et al., 2023). Regarding lack of compensation by the government for dead pigs and prioritizing household income earnings, farmers perceived selling of sick animals as the best option to realize some funds from their pigs rather than to leave them to die of ASF during outbreaks (Nantima et al., 2016; Dixon et al., 2020). Farmers and other actors' business transactions, and with weak biosecurity implementation, pose high risk of ASF spread in smallholder pig value chain (Nantima et al., 2015a; Nantima et al., 2015b; Dione et al., 2018), yet pig value chain actors are expected to join government in ASF control. The O3 in this study assessed actions taken by different stakeholders and the perceived economic impact during quarantine. The findings show that stakeholders shifted their trade activities from formal to informal marketplaces, free of regulation. Farmers' homestead provided both live pigs and pork delivered to targeted clients. Impact of quarantine was perceived to be higher among farmers followed by pork retailers more than other stakeholder namely: middlemen, tax-collectors, consumers, and veterinarians. Farmers were heavily impacted due to death of pigs, sale of pigs cheaply in panic, and excess cost of feeding pigs due to delayed sale.

8.2.4 Economic impact of quarantine imposition on smallholder value chain (O4)

The negative economic impacts of ASF in a large farm is always greater than in a smallholder farm (Nguyen-Thi et al., 2021) due to high level of investment cost such as in O4 which had over five thousand pigs and excellent facilities. Low biosecurity level, common in pig production system characterized by low input or low-output operation (Mutua & Dione, 2021) typical of smallholder such as in O1 has been associated with farmers' lack of interest to invest in biosecurity and failure to recognize benefit of controlling and preventing ASF outbreaks in their farms (Ebata et al., 2020a). Investment in farm biosecurity reduces farmers' profit margin (Fasina et al., 2012a; Ouma

et al., 2018). One major factor limiting adoption of biosecurity measures by poor farmers and other smallholder value chain actors is their limited financial resources. It remains a big challenge to have a practical, feasible and sustainable solutions suitable for local settings, and designing risk mitigation interventions along smallholder pig value chains that will not impact on the sector negatively (Penrith, 2020). Similarly, it may be impossible for smallholder value chain actors to implement interventions associated with loss of their income.

The O4 of this study analyzed economic impact of quarantine imposition on smallholder value chain during ASF outbreak. Closure of designed slaughter slabs caused loss of farmers' revenue an equivalent of the value of pigs which missed being slaughtered in those slaughter slabs during trade ban. Subsequently, traders revenues were negatively affect because pork quantity an equivalent of pig carcass forgone when slaughter slabs were closed during trade ban. These losses of revenue among actors was grater among trader than farmers. Using SD modelling, inventories of pigs and pork dropped and their respective prices increases during trade ban when consumers demand remained unchanged, but inventories of pig rises and for pork remained low leading to a drop in all prices when consumers demand diminishes during trade ban. Profit increases marginally among traders and farmers during trade ban with no change in consumers demand, but their profit decreases during trade ban when consumers demand decreases. The decreased profit margin was much greater in farmers more than for traders. There was epidemiological benefits since pig herd increases in all cases during trade ban, whether consumers demand decreases or not.

8.3 General discussions

This study discussion provides an insight into implementation and economic perspectives of biosecurity measures, deployed in ASF prevention and control in both smallholders and large-scale commercial farms in Uganda. Poor implementation of total confinement of pigs within pigsty to control pig movement or avoid pigs encountering ASFV contaminated materials/infective tissues and sick pigs in the environment has remained a big challenge in Uganda. In studies which targeted smallholders, pig confinement is implemented by enclosing free roaming pigs during ASF outbreak periods (O1) and quarantine imposition (O3 and O4). During quarantine, pig and pork movement in villages reduce as trade restriction lowers number of pigs which farmers supply the market (O4). In large scale commercial farm (O2), pigs confined within production units follow

certain routine movements within and across houses such as a “circular movement” driven by breeding process within Breeding Section. The breeding process involves transfers of gilts and weaned sows from RGRH and Farrowing Houses, respectively, to AI-Station for insemination (using semen collected from boars located in Boar Station), transfer of inseminated gilts and sows from AI-Station to DSHs, and transfer of pregnant sows and gilts from DSHs to Farrowing Houses. Adoption of pigs confinement at all times and in all seasons increases with high herd size and from rural to peri-urban and urban setting has been demonstrated in Uganda (Muhanguzi et al., 2012; Ouma et al., 2014). In O1, the suspension of buying breeding stock and borrowing breeding boar during ASF outbreaks further showed that smallholder farmers are interested in controlling ASF (Chenais et al., 2023a). When there is no ASF outbreak (O1), the reported practice of borrowing breeding boars from farmers with history of good pig management practice, and the isolation of newly bought pigs for 14 days as demonstrated by Chenais et al., (2023a) indicating that smallholder farmers are aware of risk posed by movement of breeding pigs.

However, the low level of internal biosecurity and direct contact between pigs associated with continuous pig movement within and across houses (O2), and pig movement across villages due to trade in smallholder value chain (from formal to informal markets in O3), could have contributed to lengthening of epidemic periods in O2, O3, and O4. Epidemic periods lasted for 41 and 93 days during 2021 and 2022 ASF outbreaks, respectively in RO2, and for much longer periods (213 days in O3 and 275 days in O4) during quarantine. The long epidemic periods in the study farm (O2) indicates rather slow spread of ASF within the farm, similar observation was reported elsewhere (Chenais et al., 2019b; Lamberg et al., 2020). Furthermore, the introduction of ASFV, and its maintenance within the IMF for long shows that having hardware biosecurity components such as equipment, standard pigsty, fences and gates) described by Chenais et al. (2019b) alone could not prevent outbreaks or control ASF spread in the farm. Software biosecurity associated with human element such as mindset, routine hygiene practices, human behaviors or activities, and acceptability of biosecurity suitable to local settings) described by Chenais et al. (2019b), complements hardware biosecurity during prevention and control of ASF along the value chain.

Human activities or behaviors which compromise the implementation of biosecurity protocols in O2 could have facilitated the introduction and spread of ASFV in the farm. Feed contamination was suspected as a possible source of viral introduction in the farm following laboratory

confirmation of ASFV in feeds sampled from IMF. Though it was the samples of feeds delivered to IMF that tested positive for ASFV, the possibilities of laboratory contaminations or false positive (due to human activities) showed the unlikelihood of feeds introducing ASFV in large scale commercial farm. Other possible source of viral introduction could be the contaminated fomites via vehicles (IMF and farmers' trucks) which entered the farm. Production unit workers who possibly came in contact with such contaminated fomites during loading and offloading processes were likely to have indirectly conveyed ASFV to pigs in the units. The activities in Ramp-I remains the most likely access point through which ASFV could have entered Biosecurity Level-II from Biosecurity Level-I. This is supported by the strong association ($P < 0.001$, calculated using Odds ratio) between Ramp-I location and number of deaths in 'early infected pig houses. In this case, Ramp-I is 7m from Dry Sow Houses where index cases were identified during both 2021 and 2022 ASF outbreaks in IMF.

As a result of human behaviors in O1 study, local culture and traditional beliefs were found to hinder implementation of biosecurity measures. As culture prohibits burial of dead pigs, traditional belief of the community allows for eating pork from such dead pigs, a practice also reported in O3 during quarantine. Culture and traditional beliefs observed in this study, contribute to socio-economic factors such as pig herd size associated with ASF outbreaks in the domestic cycle (Chenais et al., 2017b). Reliance on current knowledge of the epidemiology of the disease without considering socio-economic or cultural factors is partially responsible for lack of compliance with policy regulations such as quarantine imposition aimed at limiting spread of ASF (Dixon et al., 2020). A shift in trade activities by smallholder stakeholders from formal to informal market setting during quarantine, influenced consumers demand (O4), with regulating authorities limiting their enforcement to formal market as observed in O3, support the perception of limited access to veterinary service hindering control of ASF by smallholder farmers in Uganda in O1. The privatization of veterinary services in Uganda does not favor poor smallholder livestock farmers who may not afford payment for the service. In sub-Saharan Africa, veterinary services and advice are tailored to benefit commercial and large-scale farmers (Brown et al., 2013; Amankwah et al., 2014; Okello et al., 2023). Support to family livelihood needs and sustaining income source were given priority over implementation of biosecurity measures or not complying with regulations such as trade restrictions similar with findings in O3 when actors shifted from formal to informal markets. Sales of sick or dead pigs to support livelihood needs compromises success of biosecurity

measures as the sick pigs or infective tissues can spread ASFV to a wider area and failure in controlling ASF spread.

The study findings revealed that high costs of required materials such as for disinfection, feeding and pigsty construction partially hindered implementation of biosecurity in smallholder settings (O1 and O3). But in O2, biosecurity implementation failed in a well-established large scale farm despite having facilities enough to prevent and control ASF outbreak. Although pig confinement and feeding are positively perceived as effective in prevention of ASF outbreak (O1), cost hinders their implementation strategies. Pig confinement involves construction of pigsty and fence using affordable local building materials available in the community such as grass thatch roof, and walls made of tree poles. Cost of pigsty construction has been mentioned in both O1 and O3 of this study. Whereas farmers can access local materials from the bushes free of charge as in O1, there are other costs of buying manufactured material such as axes, sickles and nails which make pigsty construction relatively expensive and unaffordable for some farmers as observed in O3. Unaffordable cost of buying feeds make farmers allow their pigs to scavenge on any feeds during quarantine period. Farmers release confined pigs to scavenge or feed them on swill due to high cost of feeds associated with increasing scarcity of conventional and commercial feed resources or in dry season (Tatwangire, 2014; Okello et al., 2021; Dixon et al., 2020). Previous study reported that resource poor farmers make minimal investment in pig production (Muhanguzi et al., 2012) and disease control. It has been reported that ASF control strategies should consider options and solutions that are feasible and pro-poor (Dione et al., 2020).

In O3 of this study, farmers were perceived most affected followed by pork retailers whenever quarantine was imposed to control ASF spread. However, O4 of this study revealed details of economic losses across actors when all designated pig slaughter slabs, and pork retail facilities remain closed for seven months in response to ban on sales of live pigs and pig products. The total number of 1,602 live pigs not slaughtered on slaughter slabs during period of trade ban, estimated to be \$160,200 worth of live pigs which farmers would have sold or \$176,576 worth of 44,144 kg of pork traders would have sold as raw pork, demonstrated that traders were mostly affected economically more than farmers. Following business practice, traders sell pork at a price which is enough to gain profit out pigs bought from farmers. Traders' economic losses would even be much higher if the study considered pork and trotters (pigs' legs) sold in roasted form. Traders make

profit during ASF outbreaks as they buy pigs cheaply and sell pork at normal market price (Chenais et al. 2017b). This financial loss could have been exacerbated by the high number of pigs expected to be slaughtered in 2022 festive season and from four public holidays in 2023, all of which took place during the quarantine period.

Perceived additional cost of feeding confined pigs previously on free range and pigs from delayed sale during quarantine contributed to farmers' losses (O3). In O4, the low sales of pigs due to trade restriction contributed to the drop in farmers profit margin during trade ban. Similarly, the low pig sales causes increase in number of adult pigs (marketable pigs) in the farm, as a result, farmers incur cost of feeding the expanding pig herd size. Farmers profit margins lowered further in a scenario where increasing the farm biosecurity cost during trade ban leads to further increase in pig herd size due to reduced death rates. Previous study reported that, the cost of implementing biosecurity measures at farm level lowers farmers profit margin despite reduction in ASF incidence (Ouma et al., 2018). It is challenging for poor farmers to maintain in ASF incidence in pig farm without threatening their livelihoods, aimed at having a sustainable and profitable pig production (Penrith et al., 2019). With occurrence of animal disease outbreak, the impacts associated with disease itself and control affect farmers and other actors all along the value chain differently (Rich & Wanyoike 2010).

8.4 General conclusions

- i) The current biosecurity measures failed as hinderances outweigh enablers of ASF prevention and control.
- ii) Provision of all the recommended biosecurity requirements alone, without observing strict routine biosecurity protocols, render prevention and control of ASFV introduction into and spread within the farm impossible.
- iii) Authorities implemented mandatory quarantine regulations in formal market places, but trade continues in informal marketplaces.
- iv) Reducing the pig mortality rates through enhanced biosecurity can improve pig herd protection during trade, but there is a trade-off with greater incurred costs.

8.6 General recommendations

- i) Achieving ASF prevention and control require exploration of careful adoption of biosecurity advice in participation with end users, compatibility with local traditions, culture, livelihoods and the socioeconomic context.
- ii) Irrespective of farm-scales, adherence to strict internal biosecurity and more awareness regarding hygiene practices is critical for ASF prevention and control.
- iii) Continuation of trade in informal markets needs to be addressed for effective control of ASF break during trade bans.
- iv) Reducing the pig mortality rates through enhanced biosecurity can improve outcomes from ASF outbreaks but there is a trade-off with greater costs to be incurred.
- v) Enhanced biosecurity measures is epidemiologically more beneficial than trade ban, but due to relative drop in profit margins, the trade ban could be more appropriate in smallholder settings.

8.5 Study contributions

- i) Categorization of enablers and hinderances of biosecurity implementation provides areas of focus aimed at improving ASF prevention and control.
- ii) ASFV contaminated commercial feeds is always neglected as a probable source of ASF introduction into the farm.
- iii) Methodologically, the participatory process in data collection, analysis and validation enabled the study to explore ASF economic impact of quarantine at a much more detail levels than ever been done before.

8.6 General recommendation for further research

- i) Future research that integrates epidemiological models such as Susceptible-Infectious-Recovered (SIR) directly within an SD framework will provide greater details on the impacts of different outbreaks and their feedback from production and marketing on the evolution of outbreaks themselves.

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APPENDICES

Appendix 4.1: FGD topic guide in a study conducted in greater Gulu

Outline

- 1) Present the project, its objectives and the project team
- 2) Explain the consent form and confidentiality, ask for permission to take photographs and make recordings
- 3) Complete the background data sheet and consent forms and pay the transport fee
- 4) Start the discussion

Material needed

Background data sheet, flipchart, scotch tape, markers, notebook, pen, digital recorder, refreshments

Time started _____ ***Time ended*** _____

Interview/topic guide

Warm-up

Have you or the village been affected by African swine fever?

When was the last time this happened?

Is there anything you would like to say about the outbreak(s)?

We are going to talk a bit about today what you did before and during that outbreak.

Control and prevention

Did/do you try to prevent ASF from entering your village?

How did you do that?

(list all the prevention measures mentioned on the flipchart)

What worked well and why?

What didn't work well and why?

When there was African swine fever in the village, what did you do?

(list all the control measures mentioned on the flipchart)

What worked well and why?

What didn't work well and why?

Appendix 4.2: Coding of transcripts from FGD in a study conducted in greater Gulu

Extracts from transcripts	Primary codes	Themes	Categories
Houses have different standards Survival of pigs depends on house standards Houses should have a fence Fences stop stray pigs House with compartments Wide gaps in the wall can allow stray pigs to meet indoor pigs nose to nose	Biosecurity measures	Pigs can be confined in houses or by fences, and these can be constructed in different ways.	ASF biosecurity measures perceived as effective
Pigs should not be released from their houses when feed is scarce Other people won't touch pigs People who step in faeces don't enter	Biosecurity measures	Confining pigs prevents contact with other pigs and people	
Pigs moving around Movement restrictions Movement restrictions Restrict movement so infected bones aren't eaten Pigs move to eat Moving stray pigs can be contaminated Stray pigs cannot be chased at night when you're asleep Movement of stray pigs No mixing with stray pigs Stray pigs meet with tethered pigs They should not meet sick stray pigs Pigs do not move from the house to come into contact with saliva & froth from sick pigs Pigs move outside to eat anything Tethered pigs drink running water	Biosecurity measures	Restrict pig movements to control what the pigs eat, and avoid contact with stray pigs and contaminated items	

Not tempted to move if fed well Stops pigs from eating swill Satisfied pigs don't move			
Health status not disclosed Alerting neighbouring pig farmers to improve pig management and reduce frequency of eating pork during ASF outbreak	Biosecurity measures	Disclosing animal health status	
Have local bylaws	Laws should be used to improve biosecurity implementation	Implementation of local punitive measure	
ASF is airborne ASF is airborne ASF is airborne Wind will blow ASF into your home without you knowing	Airborne	ASFV can be transmitted by the wind	Local knowledge of ASF transmission
Wind will not blow ASFV from carcasses dumped in the swamp	Temperature	Damp ASFV cannot be blown from carcasses dumped in the swamp	
Ash of burnt carcasses can transmit ASF Flies from dumped carcasses might fly back to the house	Transmission sources	Flies and wind can carry infective materials	
Contaminated bones Dogs bring home the contaminated bones of unburied pigs Pigs can access and eat the incompletely burned carcasses Pigs and dogs can dig up buried carcasses You can bring home pork and throw out leftovers Children eat & throw bones around People can throw out offal ASF can be avoided if you don't bring pork home Unknowingly buy infected pork	Transmission sources	Dogs, pigs and people can bring contaminated pork or bones	

Don't feed on leaves to eliminate risk of spread from urine and faeces Sweet potatoes leaves contaminated with urine and faeces can be fed to pigs Bringing leaves contaminated with saliva and urine Stray pigs contaminate nearby swamp water Contaminated running water Stray pigs contaminate water & feeds You bring contaminated feeds into the house Faeces can contaminate feeds in sleeping area You can bring contaminated feeds	Transmission sources	Feed and water contaminated with urine, faeces and saliva	
People step on faeces and enter the house Faeces on their feet Uncleaned faeces cause pigs problems People step on blood People can touch your pigs People enter the house	Transmission sources	People contaminated with faeces and blood	
Borrowing boars Boars run away to mate Boars move within villages Stray boars allowed to mate with your pigs	Transmission sources	Borrowing breeding boar for mating	
Eat pork from centre & prepare feeds without washing hands Handling pigs and not washing hands Handle pork and feed pigs with unwashed hands Not properly washed You wash hands & give water to pigs	Transmission sources	Contaminated unwashed hands handling feeds and pigs	
Wheelbarrows carry maize contaminated with urine or saliva	Transmission sources	Use of contaminated utensils, farm tools and protective gear	

Wheelbarrows used in the garden at home and in the pig unit Borrowed saucepan carried pork Use the same saucepan to carry pork and water for pig Unclean water & bucket make pigs sick Use cloth and leave in pig house			
Butcher moves around villages Butcher moves around villages using the same cloth Butcher moves with blood on his body Butcher slaughters sick pigs Contamination from slaughter place Might touch sick pigs without buying	Transmission sources	Middlemen and slaughterers can transmit disease	
Don't buy pigs from outside to keep yours healthy Can't sell piglets to neighbours from whom you can buy piglets after outbreak	Transmission sources	Trade in live pigs can transmit the disease	
Vets might have sick pigs Vets reuse contaminated needles	Blaming vets	Vets can transmit	
Keep pigs cool to stop them dying Healthy pigs survive in cool swamp High temperature in the house kills pigs	Temperature	Cool temperatures protect pigs, heat kills ASFV	
Footbath kills virus on the boots not hair and cloth Use ash on doorstep to disinfect Washing hands and legs with jik kills bacteria	Biosecurity measures	Disinfection using ash and jik	
You can maintain good hygiene Staying close to remove faeces immediately	Biosecurity measures	Basic hygiene	

IMO adoption that destroys faeces and urine	Biosecurity measures	IMO technology adoption	
Put on boots and leave at site Have gumboots and wash house Use of wheelbarrows & spade	Biosecurity measures	Leaving farm tools and protective gear at the pig stables	
Isolation of sick pig that was with the rest Isolation, healthy survive, sick die Tie a sick pig under a tree far away Relocation of healthy pigs Pigs in the same compartment all die Late isolation of sick pigs can't guarantee the health of the remaining pigs	Biosecurity measures	Isolating sick or relocating healthy pigs	
Pigs fed on a balanced diet fight all disease Eat clean feed, no disease Eat clean feed inside Enough feeds all year round Keep pigs without buying feed Pigs survive on leaves Pigs fed on leaves alone don't grow	Feeds	Feed quality and quantity is important for good health and fast growth	
Poverty Unaffordable disinfectant Expensive to buy fuel for burning Expensive to buy paraffin Burning requires firewood or petrol Expensive fuel for burning Affordability of building materials Some pig houses are expensive to build Insufficient money to clean house You give free swill to pigs Taking swill from kitchen to pig house Financial constraints with feed Difficult to get feed	Costs hinder implementation of biosecurity	Disinfectants, cleaning materials, building materials, fuel, and feed are unaffordable	Implementation of biosecurity is partially hindered by cost

Poor people can't buy feed Pigs are left free range due to unaffordable feed Poor people cannot afford disinfectant Difficult to buy disinfectants			
Slaughter to eat Slaughter the sick pig and give to children Slaughter in the village during outbreak People sell pork in the community Sell pork to avoid losses People don't throw away adult pigs Maybe piglet carcasses are dumped Dead pigs have not been buried	Coping mechanisms	Carcasses are consumed at home or sold to raise some money and avoid total losses	Priority given to livelihoods
Sell sick pigs so as not to contaminate the rest Farmers sell when pigs are sick Selling sick pigs transfers ASF Sell to get money Sell to get money Sell to recover money People sell to get money Sell mature pigs to keep money Farmers sell to get some money Money lets butcher enter the house Poverty make people sell to get something Sell the healthy pigs during outbreak Pigs are sold before outbreak Later buy survivors from neighbours	Coping mechanisms	Trade in live pigs to protect the healthy ones, raise some money and avoid total losses	
People like pork Everybody likes meat People need to eat meat You need to eat pork People will eat buried pork Eat from the hotel People eat contaminated pork	Pork	People bring pork home to eat	

I might not buy pork but neighbours can bring pork home People come & buy meat People are buying pork People buy pork from outside & bring it home People buy this pork			
Butchers buy pigs Sick pigs bought by butchers can die before reaching the slab Butchers buy cheap pigs during outbreak Butchers buy cheap sick pigs Hard for a butcher to identify sick pigs Butchers & middle men buy sick pigs	Blaming butchers	Butchers and middlemen make a profit during outbreak	
Selling sick pigs transfers ASF Buyers can bring in disease on their contaminated clothes Buy sick pigs unknowingly Buying pigs from unknown source	Transmission sources	Selling sick pigs poses risk of ASF spread	
Some people accept bringing swill People don't bury Acholi culture doesn't accept burial Other animals can be buried, but not dogs Burial is bad in the African tradition Culture doesn't allow burial, taboo Other animals will die Rains can disappear for a year when dogs are buried	Burial	Burial of animals is forbidden in the Acholi culture and tradition	Local culture and traditions
Digging a grave is hard	Burial	It is hard work to dig a grave	
Burial is painful Like burying a human being Stray pigs or people might be exhumed if not well buried	Burial	It is psychologically painful because it reminds you of burying loved ones	
Jealous people throw bones in the house	Jealousy	People can throw bones, pork, and intestines in	

Jealous people can throw bones Jealous people throw bones and pork People can throw carcasses Neighbours buy and throw bones Stop people from throwing bad things Intestines thrown to dogs Someone can bring infected bones after a large pig has been sold		the house to deliberately infect your pigs	
You follow the vet's advice Vets give advice to avoid ASF	Trusting vets	Smallholder farmers have access to a vet	Access and quality of veterinary services
Vets don't come out to treat ASF Vets don't make farmers aware of it	Blaming vets	Smallholder farmers don't have access to vets	
Vets advise on disinfection before entering the house Vets diagnose the disease Vets are accessible by smallholder farmers		Veterinary treatments are helping	
Pigs still die after the vet is called Vets treat the pig and it dies if it has ASF Vaccination doesn't help Calling a vet doesn't help Vets give the wrong advice	Blaming vets	Veterinary treatments aren't helping	
ASF has no cure ASF has no cure ASF has no vaccine	Hopelessness	There is no medicine or vaccine for ASF	

Appendix 5.1: Raw data for odds ratio analysis for 2021 outbreak in IMF

2021

Risk Areas	exposed group (Houses less/equals 20 meters from Risk areas)	non exposed group (Houses greater than 20 meters from Risk areas)
Ramp-I	DSH-I	BS & RGRH
Container	BS & RGRH	DSH1
Biosecurity House-I	BS	DSH1 & RGRH

Keys:

DSH-I = Dry Sow House-I; BS=Boar Station; RGRH=Replacement Gilt Rearing House. These houses (DSH-I, BS, and RGRH) are considered early infected houses.

2021

House with early pig deaths	Distances (meters) of high-risk areas from houses with early pig deaths				
	Ramp-I	Ramp-II	Container	BH-I	BH-II
DSH1	10	60	47	50	65
BS	35	30	15	20	35
RGRH	70	35	20	24	40

Key: BH-I= Biosecurity House-I; BH2= Biosecurity House-II

2021

2021: Houses where pigs died from weeks 17, 18, 19 (when ASF was suspected and confirmed) to week 20 are considered as early infected houses.			
2021 Early infected houses	Infected (#dead pigs)	Non-Infected	Total
DSH1	154	357	511
RGRH	6	95	101
BS	2	20	22

2021

Risk Areas	Exposed group		Non-exposed group	
	Infected	Non-infected	Infected	Non-infected
Ramp-I	154	357	2+6=8	95+20=115
Container	2+6=8	20+95=115	154	357
Biosecurity House-I	2	20	154+6=160	357+95=452

2021

Risk Areas	Exposed group		Non-exposed group	
	Infected	Non-infected	Infected	Non-infected
Ramp-I	154	357	8	115
Container	8	115	154	357
Biosecurity	2	20	160	452
House-I				

2021 Odd ratio

2025-03-11

```
library(epiR)

## Loading required package: survival

## Package epiR 2.0.80 is loaded

## Type help(epi.about) for summary information

## Type browseVignettes(package = 'epiR') to learn how to use epiR for applied epidemiological analyses

##

library(stats)

# Ramp-I
# Create the 2x2 table
Adjacency_data <- matrix(c(154, 8, 357, 115), nrow = 2, byrow = TRUE,
  dimnames = list("Infection Status" = c("Infected", "Not Infected"),
    "Adjacency" = c("Adjacent", "Not Adjacent")))

# Compute the odds ratio
adjacency_or <- epi.2by2(Adjacency_data, method = "cohort.count", conf.level = 0.95)
print(adjacency_or)

##           Outcome +   Outcome -   Total           Inc risk *
## Exposed +         154         8       162    95.06 (90.50 to 97.84)
## Exposed -         357        115       472    75.64 (71.50 to 79.44)
## Total             511        123       634    80.60 (77.30 to 83.61)
##
## Point estimates and 95% CIs:
```

```
## -----
## Inc risk ratio          1.26 (1.18, 1.34)
## Inc odds ratio         6.20 (2.96, 13.01)
## Attrib risk in the exposed *      19.43 (14.31, 24.54)
## Attrib fraction in the exposed (%) 20.44 (15.34, 25.22)
## Attrib risk in the population *    4.96 (0.02, 9.91)
## Attrib fraction in the population (%) 6.16 (4.22, 8.06)
## -----
## Uncorrected chi2 test that OR = 1: chi2(1) = 29.107 Pr>chi2 = <0.001
## Fisher exact test that OR = 1: Pr>chi2 = <0.001
## Wald confidence limits
## CI: confidence interval
## * Outcomes per 100 population units

# Container
# Create the 2x2 table
Adjacency_data <- matrix(c(8, 154, 115, 357), nrow = 2, byrow = TRUE,
  dimnames = list("Infection Status" = c("Infected", "Not Infected"),
    "Adjacency" = c("Adjacent", "Not Adjacent")))

# Compute the odds ratio
adjacency_or <- epi.2by2(Adjacency_data, method = "cohort.count", conf.level = 0.95)
print(adjacency_or)

##      Outcome +   Outcome -   Total      Inc risk *
## Exposed +       8       154    162    4.94 (2.16 to 9.50)
## Exposed -      115      357    472   24.36 (20.56 to 28.50)
## Total          123      511    634   19.40 (16.39 to 22.70)
##
## Point estimates and 95% CIs:
## -----
## Inc risk ratio          0.20 (0.10, 0.41)
## Inc odds ratio         0.16 (0.08, 0.34)
## Attrib risk in the exposed *      -19.43 (-24.54, -14.31)
## Attrib fraction in the exposed (%) -393.38 (-887.67, -146.46)
## Attrib risk in the population *    -4.96 (-9.91, -0.02)
## Attrib fraction in the population (%) -25.59 (-32.89, -18.69)
## -----
## Uncorrected chi2 test that OR = 1: chi2(1) = 29.107 Pr>chi2 = <0.001
## Fisher exact test that OR = 1: Pr>chi2 = <0.001
## Wald confidence limits
## CI: confidence interval
## * Outcomes per 100 population units

#Biosecurity House-I
# Create the 2x2 table
Adjacency_data <- matrix(c(2, 160, 20, 452), nrow = 2, byrow = TRUE,
  dimnames = list("Infection Status" = c("Infected", "Not Infected"),
    "Adjacency" = c("Adjacent", "Not Adjacent")))

# Compute the odds ratio
```

```
adjacency_or <- epi.2by2(Adjacency_data, method = "cohort.count", conf.level = 0.95)
print(adjacency_or)
```

```
##      Outcome +   Outcome -   Total      Inc risk *
## Exposed +         2       160     162     1.23 (0.15 to 4.39)
## Exposed -        20       452     472     4.24 (2.61 to 6.47)
## Total            22       612     634     3.47 (2.19 to 5.21)
##
## Point estimates and 95% CIs:
## -----
## Inc risk ratio                0.29 (0.07, 1.23)
## Inc odds ratio                0.28 (0.07, 1.22)
## Attrib risk in the exposed *  -3.00 (-5.49, -0.51)
## Attrib fraction in the exposed (%) -243.22 (-1352.33, 18.89)
## Attrib risk in the population * -0.77 (-3.08, 1.54)
## Attrib fraction in the population (%) -22.11 (-39.68, -6.76)
## -----
## Uncorrected chi2 test that OR = 1: chi2(1) = 3.246 Pr>chi2 = 0.072
## Fisher exact test that OR = 1: Pr>chi2 = 0.083
## Wald confidence limits
## CI: confidence interval
## * Outcomes per 100 population units
```

2021				
		95% CI		
	OR	Lower	Upper	P value
Ramp-I	6.20	2.96	13.01	<0.001
Container	0.16	0.08	0.34	<0.001
Biosecurity House-I	00.28	0.07	1.22	0.072

Appendix 5.2: Raw data for odds ratio analysis for 2022 outbreak in IMF

2022		
Risk Areas	exposed group (Houses less/equals 20 meters from Risk areas)	non exposed group (Houses greater than 20 meters from Risk areas)
Ramp-I	DSH-I	BS & RGRH
Container	BS & RGRH	DSH-I
Biosecurity House-I	BS	DSH1 & RGRH

Keys:

DSH-I = Dry Sow House-I; BS=Boar Station; RGRH=Replacement Gilt Rearing House. These houses (DSH-I, BS, and RGRH) are considered early infected houses.

2022					
House with early pig deaths	Distances (meters) of high-risk areas from houses with early pig deaths				
	Ramp-I	Ramp-II	Container	BH-I	BH-II
DSH1	10	60	47	50	65
BS	35	30	15	20	35
RGRH	70	35	20	24	40

Key: BH-I= Biosecurity House-I; BH-II= Biosecurity House-II

2022			
2022 : Houses where pigs died from week 15 (when ASF was suspected and confirmed) to week 17 are considered as early infected houses.			
2022 Early infected houses	Infected (#dead pigs)	Non-infected	Total
DSH1	81	284	365
RGRH	3	13	16
BS	14	2	16

2022				
Risk Areas	exposed group		non exposed group	
	Infected	Non-infected	Infected	Non-infected
Ramp-I	81	284	3+14=17	13+2=15
Container	14+3=17	2+13=15	81	284
Biosecurity House-I	14	2	81+3=84	284+13=297

2022				
Risk Areas	Exposed group		Non-exposed group	
	Infected	Non-infected	Infected	Non-infected
Ramp-I	81	284	17	15
Container	17	15	81	284
BH-I	14	2	84	297

2022 Odd ratio

2025-03-11

```
library(epiR)

## Loading required package: survival

## Package epiR 2.0.80 is loaded

## Type help(epi.about) for summary information

## Type browseVignettes(package = 'epiR') to learn how to use epiR for applied epidemiological analyses

##

library(stats)

# Ramp-I
# Create the 2x2 table
Adjacency_data <- matrix(c(81, 17, 284, 15), nrow = 2, byrow = TRUE,
  dimnames = list("Infection Status" = c("Infected", "Not Infected"),
    "Adjacency" = c("Adjacent", "Not Adjacent")))

# Compute the odds ratio
adjacency_or <- epi.2by2(Adjacency_data, method = "cohort.count", conf.level = 0.95)
print(adjacency_or)

##           Outcome +   Outcome -   Total           Inc risk *
## Exposed +           81         17       98   82.65 (73.69 to 89.56)
## Exposed -          284         15      299   94.98 (91.86 to 97.17)
## Total              365         32     397   91.94 (88.81 to 94.42)
##
## Point estimates and 95% CIs:
## -----
## Inc risk ratio                0.87 (0.79, 0.96)
## Inc odds ratio                0.25 (0.12, 0.53)
## Attrib risk in the exposed *   -12.33 (-20.22, -4.44)
## Attrib fraction in the exposed (%) -14.92 (-26.29, -4.57)
## Attrib risk in the population * -3.04 (-6.69, 0.60)
## Attrib fraction in the population (%) -3.31 (-5.58, -1.09)
## -----
## Uncorrected chi2 test that OR = 1: chi2(1) = 15.142 Pr>chi2 = <0.001
## Fisher exact test that OR = 1: Pr>chi2 = <0.001
## Wald confidence limits
## CI: confidence interval
## * Outcomes per 100 population units

# Container
# Create the 2x2 table
Adjacency_data <- matrix(c(17, 81, 15, 284), nrow = 2, byrow = TRUE,
  dimnames = list("Infection Status" = c("Infected", "Not Infected"),
```

```

"Adjacency" = c("Adjacent", "Not Adjacent"))))

# Compute the odds ratio
adjacency_or <- epi.2by2(Adjacency_data, method = "cohort.count", conf.level = 0.95)
print(adjacency_or)

##           Outcome +   Outcome -   Total           Inc risk *
## Exposed +           17           81       98    17.35 (10.44 to 26.31)
## Exposed -           15          284      299     5.02 (2.83 to 8.14)
## Total              32          365      397     8.06 (5.58 to 11.19)
##
## Point estimates and 95% CIs:
## -----
## Inc risk ratio                3.46 (1.79, 6.66)
## Inc odds ratio                3.97 (1.90, 8.30)
## Attrib risk in the exposed *   12.33 (4.44, 20.22)
## Attrib fraction in the exposed (%) 71.08 (44.28, 84.99)
## Attrib risk in the population * 3.04 (-0.60, 6.69)
## Attrib fraction in the population (%) 37.76 (11.29, 56.33)
## -----
## Uncorrected chi2 test that OR = 1: chi2(1) = 15.142 Pr>chi2 = <0.001
## Fisher exact test that OR = 1: Pr>chi2 = <0.001
## Wald confidence limits
## CI: confidence interval
## * Outcomes per 100 population units

#Biosecurity House-I
# Create the 2x2 table
Adjacency_data <- matrix(c(14, 84, 2, 297), nrow = 2, byrow = TRUE,
  dimnames = list("Infection Status" = c("Infected", "Not Infected"),
    "Adjacency" = c("Adjacent", "Not Adjacent")))

# Compute the odds ratio
adjacency_or <- epi.2by2(Adjacency_data, method = "cohort.count", conf.level = 0.95)
print(adjacency_or)

##           Outcome +   Outcome -   Total           Inc risk *
## Exposed +           14           84       98    14.29 (8.04 to 22.81)
## Exposed -           2          297      299     0.67 (0.08 to 2.40)
## Total              16          381      397     4.03 (2.32 to 6.46)
##
## Point estimates and 95% CIs:
## -----
## Inc risk ratio                21.36 (4.94, 92.32)
## Inc odds ratio                24.75 (5.52, 111.06)
## Attrib risk in the exposed *   13.62 (6.63, 20.61)
## Attrib fraction in the exposed (%) 95.32 (79.76, 98.92)
## Attrib risk in the population * 3.36 (1.22, 5.51)
## Attrib fraction in the population (%) 83.40 (39.77, 95.43)
## -----
## Yates corrected chi2 test that OR = 1: chi2(1) = 31.950 Pr>chi2 = <0.001

```

Fisher exact test that OR = 1: **Pr>chi2 = <0.001**

Wald confidence limits

CI: confidence interval

* Outcomes per 100 population units

2022

		95% CI		
	OR	Lower	Upper	P value
Ramp-I	0.25	0.12	0.53	<0.001
Container	3.97	1.90	8.30	<0.001
Bio1	24.75	5.52	111.06	<0.001

Appendix 5.3: Pens in DSH-I partitioned using metallic bar rails in IMF



Appendix 6.1: Key Informant Interview (KII) guides in Kisoro/Moyo districts

Target: District Veterinary Officers (DVO)

This courtesy call on your office is in regards to quarantine imposed here in the past. We are conducting a study on implementation and economic impact of past quarantine along pig value chains in Kisoro and Moyo districts. The findings and recommendations from this academic study will guide the Government on future actions to improve pigs and pork movement restrictions during African swine fever outbreaks. Based on this back ground, I will interview you using these few questions;

Question one:

Generally, describe the marketing dynamics of pigs and pork in your district. Mention, if any the available pig livestock markets, and sourcing for breeding stocks.

Question two:

How would you describe logically the pig value chain in the district, from farmers through different market linkages to the final pork consumer at the time of pig and pork movement restrictions?

Appendix 6.2: FGDs guides in Kisoro/Moyo districts)

Targeted Pig Value Chain Actor: **Farmers/Traders/Veterinarians**

Date _____ Starting time _____ Finishing time _____

Subcounty represented _____

Total number of participants in the group: _____

Facilitator _____ Note-taker _____

Objective

To document the information needed to design a questionnaire on the possible impacts of ASF quarantine.

Methodology

Focus group discussions

Material

Flip chart, digital camera, counters (bean seeds), markers, manila paper, masking tape, rulers, sodas and water, biscuits

Introductory section: by facilitator

1. Greet the participants and request one member to open with a word of prayer.
2. Self-introduction on both sides (participants and team members).
3. Setting the scene: Introduce the project, highlighting the objectives and the important role of the participants in meeting the objectives.
4. Take them through the planned process of the focus group discussions.
5. Take them through the consent form
6. Ask for consent to use tape recorders and cameras (if any).
7. Set the ground rules together with them.

A. Identification of ASF - quarantine control measures

1. Which ASF control measures were imposed by the Government authorities to implement the quarantine? (List the control measures on flip chart).
2. Why was the control measure imposed?
3. What actions/measures did you take following imposition of control measures?

B. Experience on the Impact of the latest ASF quarantine

1. Who were the affected pig Stakeholders? (listing)
2. Rank the effects of ASF on the listed stakeholders in the order of relative monetary losses and give reasons for your decisions. [Probe into detail cost implication (cost incurred and

cost forgone) in relation to; implementation of the imposed control measures; live pigs and pork]

3. Give reasons for your decisions on the ranking in #2

Appendix 7.1: Workshop program for GMB in Moyo district

<u>DAY ONE: 6TH MAY 2024</u>		
Meeting with farmers (5), traders/butchers(3), Pork-joint owners (3) and Pork consumers (3)		
Objectives:		
- Participants introduced to research goal - Participants understand System Dynamic (SD) and Group Model Built (GMB) process and expected outcomes		
Time	GMB Script	Responsible person
8:00 – 8:10am	Assembling materials in the room: Pens, books, flip charts, manilla cards (size-A4) of different colors, masking tape, water, snacks desks, projector, and printer were set ready	Notes taker/recorder Facilitators
8:10 – 8:15am	Participants registration and supply with name tags (colour of tag representing category of participants; Farmers (green), Traders (yellow), pork-joint owners (pink) and consumers (red).	All
8:15 – 8:30am	- Participants introductions by category. - Hopes and Fears cards pinned on whiteboard and clustered into similar groups by assistant facilitator. - Facilitators summarises hopes & fears raised	All
8:30 – 10:00am	Introduce background & develop workshop goal. <u>Parameter elicitation:</u> Bring out opinions, facts, etc to develop variables; - Problems linked to ASF control failure - Ranking the first two problems - Causes & consequences of each problem	Facilitators Modelers Notes taker
10 – 10:30am	BREAK TEA	All
10:30am – 1:30pm	-Introduce terminology of stocks, flows, converters, connectors and feedback loops as common tools used to describe the pig value chain (PVC) and impacts of African Swine Fever (ASF). <u>Parameter elicitations continue</u> - Introduce GMB process - Participants build their own model	Facilitators Modelers Notes taker Core participants
1:30 – 2:00pm	LUNCH	All
1:40pm	First Day meeting adjourned to afternoon of next day	All
<u>DAY TWO: 7TH MAY 2024</u>		
Meeting with farmers (5), traders/butchers(3), Pork-joint owners (3) and Pork consumers (3)		
Objective:		
- Use of SD and GMB in assessing ASF impact along VC - Participants identify parameters and generate respective values		
8:00 – 8:10am	Assembling materials in the room: Pens, books, flip charts, masking tape, water, snacks desks, projector, and printer are all ready	Recorder Facilitators Modeler
8:10 – 8:15am	Participants registration and supply with name tags (colour of tag representing category of participants)	All
8:15 – 8:30am	Welcome remarks, recap of previous workshop, and program for day two	Facilitators Notes taker
8:30 – 10:00am	Split participants into two groups: -Farmer/Consumers group (7 participants: 5 farmers & 2 consumers). -Traders/Butchers/Consumer group (7 participants: 3 traders, 3 butchers & 1 consumer) - Parameter Booklet Script will be given to corresponding groups.	All

	- Each group will occupy different corners to allow them populate parameter values. - Facilitators and modelers will move to different to guide them where they seem stuck.	
10:00 – 10:30pm	BREAK TEA	All
10:30 – 1:30pm	-Groups' participants present their values generated for different parameters. -All core participants will discuss and have a realistic values agreeable by all members across the two groups. Note: For various biosecurity costs, only those that participants will agree are being used will be considered as parameters to run baseline scenario. The rest will be incorporated under other scenarios	All
1:40pm	Second Day workshop adjourned	

Appendix 7.2: Farmers' question scripts during GMB in Moyo district

S/N	Scripts	Value
1	Number of piglets born (litter size) to a sow/gilt at every farrowing	
2	Number of times a sow/gilt farrows per year	
3	Number of breeding sows available within 12 months	
4	Numbers of months a breeding sow is kept in the farm before selling	
5	Number of breeding boars available within 12 months	
6	Numbers of months a breeding boar is kept in the farm before selling	
7	Numbers weeks piglets are kept in farm before weaning	
8	Number of weeks weaners take to reach mature age ready for slaughter	
9	Number of weeks matures pigs take before traders/butchers come to buy	
10	Proportion of piglets sold to other farmers for breeding purpose within 12 months	
11	Proportion of piglet retained to mature for sale to traders/butchers for slaughter within 12 months	
12	Rate of selling piglets (after how many weeks)	
13	Current price of piglets	
14	Price of a piglet before ASF outbreak	
14	Price of sick piglet during ASF outbreak	
16	How many weeks did outbreak last before quarantine was imposed	
17	Price of a piglet during quarantine	
18	How many weeks did quarantine last before lifting	
19	Current price of a healthy mature pig (age in months.....)	
20	What proportion (%) of mature pigs are sold to traders from DRC/SS compared with traders from Moyo/Ajumani	
21	Price mature pig for DRC/SS traders.....Moyo/Ajumani...	
22	Rate of selling mature pigs(after how many weeks)	
23	Current price of dead mature pig (age in months.....)	
24	Price of selling mature pig 12 months before ASF outbreak	
25	Price of selling mature healthy pig during ASF outbreak	
26	Price of selling mature sick pig during ASF outbreak	
27	Price of mature dead pig during ASF outbreak	
28	Price at home of 1 kg of pork from pig that died of ASF	

29	Price at home of 1 kg of pork from ASF sick pig	
30	Current cost of buying 1kg of raw pork from butcheries	
28	Current cost of buying a plate of roasted pork from pork joint	
29	Rate of eating raw pork weekly	
30	Rate eating roasted pork weekly	
31	Price of mature pigs during quarantine	
32	Price of mature sick pig during quarantine	
33	Price of mature dead pig during quarantine	
34	Price at home of 1 kg of pork from pig that died of ASF during quarantine period	
35	Price at home of 1 kg of pork from ASF sick pig during quarantine period	
36	Proportion (%) of pigs that became sick of ASF	
37	Proportion (%) of ASF sick pigs that died	
38	Proportion (%) of ASF sick pigs that were sold	
39	Proportion (%) of ASF sick pigs that recovered	
40	Cost of buying feeds weekly	
41	Cost of transporting feeds weekly	
42	Cost involved in treatment of pigs/veterinary service within 12 months	
43	Cost of buying drugs/dewormers within 12 months	
44	Labor cost (if any) per week	
45	Other production cost (if any, list them) respectively per week	
46	One week cost of feeding confine pigs that were on free range	
47	Cost of examining health of a pig by a veterinary professional before buying	
48	Cost of fuel for burning dead disposal (Yes/No)	
49	Cost of burying dead pig (Yes/No)	
50	Cost of feeding a newly bought pig for 14 days mandatory period (Yes/No)	
51	Cost of constructing a unit to confine a newly bought pigs for 14 days mandatory period (Yes/No)	
52	Cost of constructing an isolation unit for sick pigs (Yes/No)	
53	Farm equipment is not shared with other farmers (have own) (Yes/No). Cost of buying the following and tick those being used;	
	i. Wheelbarrow:	
	ii. Spade:	
	iii. Rex:	
	iv. Hoe	

	v. Spray pump:	
54	vi. Cost of Jerrican (20Lr):	
55	Farm equipment cleaned and disinfected. Regularly cleaning of unit (Yes/No). Cost of buying the following and tick those being used;	
	i. Cost of Disinfectant 1 liter:	
	ii. Cost of Brush/Broom:	
56	Visitors use farm specific clothes and footwear (Yes/No)	
	i. Cost of an Over coat:	
	ii. Cost of a pair of Gumboot:	
57	Hand washing facilities for you and visitors before contact with pigs. Washes hands before working with pigs (Yes/No)	
	i. Cost of water tank: 20Ltr	
	ii. Cost of 1 Ltr detergent:	
58	Footbaths and disinfectants present (Yes/No)	
	i. Cost of Basin:	
	ii. Cost of 1 Ltr detergent:	
59	Control for rodents around pigs	
	i. Cost of mesh wire	
60	Having a fence as a physical biosecurity barrier to keep away roaming or stray pigs (Yes/No): Cost of constructing fence	
61	Do not feed pigs on household leftovers/Restaurant leftovers (Yes/No)	
	i. Cost of swill enough for 1 pig per day	
62	Notify pig farmers and veterinarians about ASF outbreak in your farm: Cost of buying Airtime per week	

Appendix 7.3: Traders' question scripts during GMB in Moyo district

S/N	Scripts	Value
1	How many times traders buy pigs from farmers per week currently	
2	Number of pigs bought for slaughter weekly by a trader currently	
3	Number of pigs slaughtered in metu abattoir daily currently	
4	Number of pigs slaughtered in Moyo S/c abattoir daily currently	
5	Number of days pigs are held/kept at slaughter place before slaughter currently	
6	Number of pigs slaughtered weekly by trader before ASF outbreak	
7	Number of pigs slaughtered in metu abattoir daily before ASF outbreak	
8	Number of pigs slaughtered in Moyo S/c abattoir daily before ASF outbreak	
9	How many times traders bought pigs from farmers per week before outbreak	
10	How many times traders bought pigs from farmers per week during outbreak	
11	Number of pigs slaughtered weekly during ASF outbreak but before quarantine imposition	
12	ASF outbreak lasted for how many weeks before quarantine was imposed	
13	Number of days pigs are held/kept before slaughter during ASF outbreak but before quarantine imposition	
14	Number of sick-pigs slaughtered weekly a trader during ASF outbreak but before quarantine imposition	
15	Number of days sick-pigs were held/kept before slaughter during ASF outbreak	
16	Number of dead-pigs bought weekly when there was ASF outbreak but before quarantine imposition	
17	Number of healthy pigs bought within one month when there was quarantine imposition	
18	How many times traders bought pigs from farmers weekly during quarantine	
19	Number of days bought healthy pigs are held/kept before slaughter when there was quarantine imposition	
20	How many weeks did quarantine last before it was lifted	
21	Number of sick-pigs bought within one months when there was quarantine imposition	
22	Number of days bought sick-pigs are held/kept before slaughter when there was quarantine imposition	
23	Number of dead-pigs bought within one month when there was quarantine imposition	
24	Cost of buying a mature pig currently	
25	Cost of buying a mature pigs six months before ASF outbreak	
26	Cost of buying a mature healthy during ASF outbreak but before quarantine was imposed	

27	Cost of buying mature sick pig during ASF outbreak but before quarantine was imposed	
28	Cost of buying mature dead pig during ASF outbreak but before quarantine was imposed	
29	Cost of buying a mature healthy pig when quarantine was imposed (Ugx)	
30	Cost of buying mature sick pig when quarantine was imposed (Ugx)	
	Cost of buying mature dead pig when quarantine was imposed (Ugx)	
31	Weight of a mature live pig (Kg)	
32	Weight of carcass from a mature live pig (Kg)	
33	Quantity of pork sold daily currently (Kg)	
34	Quantity of pork sold daily before ASF outbreak (Kg)	
35	Quantity of pork sold weekly during ASF outbreak but before quarantine imposition (Kg)	
36	Quantity of pork sold weekly during quarantine imposition (Kg)	
37	Proportion (%) of carcass sold to consumers in raw form daily currently	
38	Proportion (%) of carcass sold to consumers in roasted/fried form daily, currently	
39	Proportion (%) of carcass sold to consumers in raw form per daily before ASF outbreak	
40	Proportion (%) of carcass sold to consumers in roasted/fried form daily before ASF outbreak	
41	Proportion (%) of carcass sold to consumers in raw form daily during ASF outbreak but no quarantine	
42	Proportion (%) of carcass sold to consumers in roasted form per week during ASF outbreak but no quarantine	
43	Proportion (%) of carcass sold to consumers in raw form per week during six months of quarantine	
44	Proportion (%) of carcass sold to consumers in roasted form daily during quarantine imposition	
45	Price of selling 1 kg of pork from healthy pig currently	
46	Price of selling one plate of roasted pork? One Kg roasted=how many plates?	
47	How many times do you eat pork in one week	
48	Price of selling 1 kg of pork from healthy pig before ASF outbreak	
49	Price of selling 1 kg of pork from healthy pig during ASF outbreak but no quarantine	
50	Price of selling 1 kg of pork from healthy pig during quarantine	
51	Price of selling 1 kg of pork from sick pig during ASF outbreak but no quarantine	
52	Price of selling 1 kg of pork from sick pig during quarantine	

53	Price of selling 1 kg of pork from ASF dead pig during ASF outbreak but no quarantine	
54	Price of selling 1 kg of pork from ASF dead pig during quarantine	
55	Pigs examined for health by a veterinary professional before buying; Cost of for veterinary antemortem	
56	Change cloths before moving from one farm to the next (Yes/No) i. Cost of over coat: ii. Cost of gumboots:	
57	Spray over coat and gumboots before moving to the next farm (Yes/No) i. Cost of 1 litter disinfectant: ii. Cost of 1 liter spray pump:	
58	Spray transport (motorcycle) before moving to the next farm (Yes/No) i. Cost of 1 litter disinfectant: ii. Cost of spray pump:	
59	Cost incur in transporting one pig from farmer to laughter slab	
60	Cost incur in movement permit per pig	
61	Cost incur LC1 introductory letter per pig	
62	Pigs bought should be confined in the house all the time as the await slaughtering. Cost of the following; (Yes/No) i. Pigsty construction ii. 1 week feeding of a pig	
63	Slaughter pigs in the recommended slaughter slabs: (Yes/No) i. Cost of construction	
64	Maintain hygiene in the slab, and premise. Cost of all the following and tick those being used now; i. Detergent per day : ii. Disinfectant : iii. Wheel barrow: iv. Spade: v. Rex: vi. Water: vii. Brush: viii. Gloves	
65	Clean workers in the slabs. Cost of all the following & tick those being used i. Over coat: ii. Gumboots: iii. Medical checkup annually : iv. Gloves	
66	Cost of veterinary inspection fee per carcass	

67	Dispose dead pigs (Yes/No). Cost of the following; i. Fuel: ii. Digging pit	
68	Recommend Pork joint and butcheries: Cost of construction	
69	Avoid rodents in pork joints and butcheries (Yes/No). Cost of wire mesh	
70	Hygiene in the pork joint and butcheries. Cost of all the following and tick those being used; i. Detergent : ii. Disinfectant: iii. Dust bin: iv. Hand washing facility: v. Water: vi. Brush: vii. Gloves	
71	Clean workers in the pork joints and butcheries. Cost of the following; i. Over coat: ii. Gumboots: iii. Medical checkup annually: iv. Gloves	
72	Leftover should not be given to feed dogs and other animals (Yes/No). Costing i. Digging pit: ii. Fuel: iii. Labor	
73	Monthly cost of rents/hire of the following (Yes/No); i. Slaughter slab premise ii. Pork joint premise iii. Butchery premise	
74	Cost of roasted pork accompaniments per day; i. Cassava (quantlfy.....) ii. Tomatoes (quantlfy.....) iii. Onion (quantlfy.....) iv. Cabbage (quantlfy.....)	

Appendix 7.4: Equations of parameterized model structure

(001) Adjustment Time=

26

Units: **undefined**

(002) Adult dying rate=

IF THEN ELSE((Time>Outbreak start time:AND:Time<Outbreak start time+Outbreak time
) , outbreak death rate*Outbreak trigger, 0)

Units: **undefined**

(003) Adult Pigs= INTEG (

Becoming Adult-Adults dying-Slaughtering,
Customer Demand*Feeding Time)

Units: **undefined**

(004) Adults dying=

Adult Pigs*Adult dying rate

Units: **undefined**

(005) Average Breeding Time=

260

Units: **undefined**

(006) Average carcass weight=

30

Units: **undefined**

(007) Becoming Adult=

(1-Growers dying rate)*(Growers/Time to Become Adult)-Replenishing

Units: **undefined**

(008) Breeding=

(Breeding Stock*Litter per Year*Head per Litter)/52

Units: **undefined**

(009) Breeding Stock= INTEG (

Replenishing-Breeding Stock Slaughtering-BS dying,
Customer Demand*(52/(Litter per Year*Head per Litter)))

Units: **undefined**

(010) Breeding Stock Adjustment= INTEG (

change in breeding stock,
Breeding Stock Gap)

Units: **undefined**

- (011) Breeding Stock Gap=
 $(\text{Desired Breeding Stock} + \text{Perceived Breeding Stock Slaughter Rate}) - \text{Breeding Stock}$
 Units: **undefined**
- (012) Breeding Stock Slaughtering=
 $\text{Breeding Stock} / \text{Average Breeding Time} * (1 - \text{BS dying rate}) * (1 - \text{Trade ban})$
 Units: **undefined**
- (013) BS dying=
 $\text{Breeding Stock} * \text{BS dying rate}$
 Units: **undefined**
- (014) BS dying rate=
 IF THEN ELSE((Time>Outbreak start time:AND:Time<Outbreak start time+Outbreak time
), outbreak death rate*Outbreak trigger , 0)
 Units: **undefined**
- (015) Capacity Utilization=
 $\text{SMOOTH}(\text{Indicated Capacity Utilization}, \text{Adjustment Time})$
 Units: **undefined**
- (016) change in breeding stock=
 $(\text{Breeding Stock Gap} - \text{Breeding Stock Adjustment}) / \text{Gap Adjustment Time}$
 Units: **undefined**
- (017) change in demand=
 $(\text{Demand Schedule} - \text{Demand}) / \text{Demand Adjustment Time}$
 Units: **undefined**
- (018) change in short run price=
 $(\text{Pig Price} - \text{Short Term Expected Price}) / \text{Price Adjustment Time}$
 Units: **undefined**
- (019) Chemicals cost=
 0.87
 Units: **undefined**
- (020) Current inventory coverage=
 $\text{Pig Inventory} / \text{Selling Pig}$
 Units: **undefined**
- (021) Customer Demand=
 Demand
 Units: **undefined**

- (022) Demand= INTEG (
 change in demand,
 200)
 Units: **undefined**
- (023) Demand Adjustment Time=
 4
 Units: **undefined**
- (024) Demand Intercept=
 LN(Initial Demand/(Initial Pig Price^Price Elasticity of Demand)*Other Factors
)
 Units: **undefined**
- (025) Demand Schedule=
 EXP(Demand Intercept)*Pig Price^Price Elasticity of Demand
 Units: **undefined**
- (026) Demand Shock=
 -0.5*Demand trigger
 Units: **undefined**
- (027) Demand trigger=
 1
 Units: **undefined**
- (028) Desired Breeding Stock=
 Production Capacity*Capacity Utilization
 Units: **undefined**
- (029) Detergents cost at pork joint=
 0.62
 Units: **undefined**
- (030) Expected Pig Price=
 Pig Price
 Units: **undefined**
- (031) Expected price from foerign traders=
 135
 Units: **undefined**
- (032) Farm biosecurity cost per week=
 House construction cost+Labor cost+Veterinary service and dewormer cost+"Tools &
 equipment cost"
 +Water cost+Chemicals cost+Protective gears+Increased biosecurity cost

Units: **undefined**

(033) Farmers Expected Profit Margin=
Farmers total revenue/Farmers Production cost
Units: **undefined**

(034) Farmers Production cost=
Farmers total bioscurity cost+Total feeding cost per week
Units: **undefined**

(035) Farmers revenue from foriegn traders=
(Slaughtering+Breeding Stock Slaughtering)*0.6*Expected price from foerign traders
Units: **undefined**

(036) Farmers revenue from local traders=
(Slaughtering+Breeding Stock Slaughtering)*0.4*Short Term Expected Price
Units: **undefined**

(037) Farmers total bioscurity cost=
Number of households keeping pigs*Farm biosecurity cost per week
Units: **undefined**

(038) Farmers total revenue=
Farmers revenue from foriegn traders+Farmers revenue from local traders
Units: **undefined**

(039) Feed cost per pig per week=
1.2
Units: **undefined**

(040) Feed transport cost=
0.52
Units: **undefined**

(041) Feeding Time=
1
Units: **undefined**

(042) FINAL TIME = 260
Units: Week
The final time for the simulation.

(043) Gap Adjustment Time=
26
Units: **undefined**

(044) Gestation= INTEG (
 Breeding-weaning,
 Customer Demand*Gestation Delay)
 Units: **undefined**

(045) Growers= INTEG (
 Growing-Becoming Adult-Growers dying-Replenishing,
 Customer Demand*Time to Become Adult)
 Units: **undefined**

(046) Growers dying=
 Growers*Growers dying rate
 Units: **undefined**

(047) Growers dying rate=
 IF THEN ELSE((Time>Outbreak start time:AND:Time<Outbreak start time+Outbreak time
), outbreak death rate*Outbreak trigger, 0)
 Units: **undefined**

(048) Growing=
 Piglets/Time to Grow*(1-Piglets dying rate)
 Units: **undefined**

(049) Gestation Delay=
 17
 Units: **undefined**

(050) "Gumboots for abattoir & field work"=
 0.21
 Units: **undefined**

(051) Hand washing facility cost at pork joint=
 0.08
 Units: **undefined**

(052) Head per Litter=
 8
 Units: **undefined**

(053) House construction cost=
 2.08
 Units: **undefined**

(054) Increased biosecurity cost=
 5.35
 Units: **undefined**

(055) Indicated breeding Stock Change Rate=
MAX((Breeding Stock Adjustment/Growers), 0)
Units: **undefined**

(056) Indicated Capacity Utilization=
Indicated Capacity Utilization Table(Farmers Expected Profit Margin)
Units: **undefined**

(057) Indicated Capacity Utilization Table(
[(0,0)-(10,1)],(0,0),(0.3,0.4),(0.5,0.7),(1,0.8),(1.25,0.85),(1.5,0.85),(
2,0.85),(2.25,0.85),(2.5,0.875),(2.55006,0.875),(3,0.91),(3.09572,0.91),(3.24788
,0.95),(3.25,0.95),(3.5,0.98),(4,1),(4,1),(4.25,1),(5,1))
Units: **undefined**

(058) Initial Demand=
200
Units: **undefined**

(059) Initial Pig Price=
200
Units: **undefined**

(060) INITIAL TIME = 0
Units: Week
The initial time for the simulation.

(061) Inventory goal=
2
Units: **undefined**

(062) Inventory Ratio=
Perceived Inventory/Inventory goal
Units: **undefined**

(063) Labor cost=
4.99
Units: **undefined**

(064) Labor cost at abattoir=
9.36
Units: **undefined**

(065) Labor cost at pork joint=
8.11
Units: **undefined**

(066) Litter per Year=
2
Units: **undefined**

(067) Movement ban start time=
125
Units: **undefined**

(068) Number of households keeping pigs=
480
Units: **undefined**

(069) Number of traders in Moyo=
35
Units: **undefined**

(070) Other Factors=
IF THEN ELSE((Time>Outbreak start time+2:AND:Time<Outbreak start time+Outbreak
time
+2),1+Demand Shock,1)
Units: **undefined**

(071) outbreak death rate=
0.005
Units: **undefined**

(072) Outbreak start time=
120
Units: **undefined**

(073) Outbreak time=
30
Units: **undefined**

(074) Outbreak trigger=
1
Units: **undefined**

(075) Perceived Breeding Stock Slaughter Rate=
SMOOTH(Breeding Stock Slaughtering, Time to Perceive Slaughter Rate)
Units: **undefined**

(076) Perceived Inventory=
SMOOTH(Current inventory coverage, Time to Perceive Inventory)
Units: **undefined**

(077) Pig Inventory= INTEG (
 Breeding Stock Slaughtering+Slaughtering-Selling Pig,
 Customer Demand*Inventory goal)
 Units: **undefined**

(078) Pig Price=
 Initial Pig Price*Inventory Ratio^Price Elasticity Inventory Ratio
 Units: **undefined**

(079) Pig slaughter fee=
 18.92
 Units: **undefined**

(080) Pig to carass conversion ration=
 0.65
 Units: **undefined**

(081) Pig transport cost per week=
 21.62
 Units: **undefined**

(082) Piglets= INTEG (
 weaning-Growing-Piglets dying,
 Customer Demand*Time to Grow)
 Units: **undefined**

(083) Piglets dying=
 Piglets*Piglets dying rate
 Units: **undefined**

(084) Piglets dying rate=
 IF THEN ELSE((Time>Outbreak start time:AND:Time<Outbreak start time+Outbreak time
), outbreak death rate*Outbreak trigger, 0)
 Units: **undefined**

(085) "pork cooking requirements & accompaniments cost"=
 143.78
 Units: **undefined**

(086) Pork Inventory= INTEG (
 Processing pork-Selling pork,
 200)
 Units: **undefined**

(087) Pork sales rate=

- 1
Units: **undefined**
- (088) Price Adjustment Time=
12
Units: **undefined**
- (089) Price Elasticity Inventory Ratio=
-0.3
Units: **undefined**
- (090) Price Elasticity of Demand=
-0.5
Units: **undefined**
- (091) Processing pork=
Selling Pig*Average carcass weight*Pig to carass conversion ration
Units: **undefined**
- (092) Production Capacity=
(Initial Demand*1.1111)*(52/(Litter per Year*Head per Litter))
Units: **undefined**
- (093) Protective gears=
0.47
Units: **undefined**
- (094) "Quality assurance (movement permit & pork inspection) cost"=
25.41
Units: **undefined**
- (095) Raw pork price per Kg=
(Expected Pig Price*0.065)*2.8/5
Units: **undefined**
- (096) Renting pork joint premises=
7.48
Units: **undefined**
- (097) Replenishing=
Growers*Indicated breeding Stock Change Rate
Units: **undefined**
- (098) Roasted pork price per Kg=
(Raw pork price per Kg*0.05)*5*10
Units: **undefined**

- (099) SAVEPER =
 TIME STEP
 Units: Week [0,?]
 The frequency with which output is stored.
- (100) Selling Pig=
 Demand
 Units: **undefined**
- (101) Selling pork=
 Pork Inventory*Pork sales rate
 Units: **undefined**
- (102) Shelter construction cost=
 1.25
 Units: **undefined**
- (103) Short Term Expected Price= INTEG (
 change in short run price,
 Pig Price)
 Units: **undefined**
- (104) Slaughtering=
 Adult Pigs*(1-Adult dying rate)/Feeding Time*(1-Trade ban)
 Units: **undefined**
- (105) TIME STEP = 0.25
 Units: Week [0,?]
 The time step for the simulation.
- (106) Time to Become Adult=
 16
 Units: **undefined**
- (107) Time to Grow=
 5.5
 Units: **undefined**
- (108) Time to Perceive Inventory=
 2
 Units: **undefined**
- (109) Time to Perceive Slaughter Rate=
 1
 Units: **undefined**

- (110) "Tools & equipment cost"=
0.97
Units: **undefined**
- (111) Total feeding cost per week=
(Feed cost per pig per week*Total Pig population)+(Feed transport cost*Number of households keeping pigs
)
Units: **undefined**
- (112) Total Pig population=
Adult Pigs+Breeding Stock+Growers+Piglets
Units: **undefined**
- (113) Trade ban=
IF THEN ELSE((Time>Movement ban start time:AND:Time<Movement ban start time +Outbreak time), Trade ban percentage*Trade ban trigger, 0)
Units: **undefined**
- (114) Trade ban percentage=
0.5
Units: **undefined**
- (115) Trade ban trigger=
1
Units: **undefined**
- (116) Trader biosecurity cost per week=
Detergents cost at pork joint+"Quality assurance (movement permit & pork inspection) cost"
+Labor cost at abattoir+Shelter construction cost
+Hand washing facility cost at pork joint+"Water (hand washing) cost"+"Gumboots for abattoir & field work"
Units: **undefined**
- (117) Traders business related costs per week=
(Slaughtering+Breeding Stock Slaughtering)*Expected Pig Price+Labor cost at pork joint
+Pig transport cost per week+"pork cooking requirements & accompaniments cost"
+Renting pork joint premises+Pig slaughter fee
Units: **undefined**
- (118) Traders Expected Profit Margin=
Traders total revenue/Traders total production cost
Units: **undefined**

- (119) Traders overall bioscurity cost=
 Trader biosecurity cost per week*Number of traders in Moyo
 Units: **undefined**
- (120) Traders revenue from raw pork=
 Raw pork price per Kg*Selling pork*0.2
 Units: **undefined**
- (121) Traders revenue from roasted pork=
 Roasted pork price per Kg*Selling pork*0.8
 Units: **undefined**
- (122) Traders total production cost=
 Traders business related costs per week+Traders overall bioscurity cost
 Units: **undefined**
- (123) Traders total revenue=
 Traders revenue from roasted pork+Traders revenue from raw pork
 Units: **undefined**
- (124) Veterinary service and dewormer cost=
 0.23
 Units: **undefined**
- (125) "Water (hand washing) cost"=
 0.31
 Units: **undefined**
- (126) Water cost=
 0.62
 Units: **undefined**
- (127) weaning=
 Gestation/Guestation Delay
 Units: **undefined**

Appendix 7.5: Baseline parameters generated by participants during GMB in Moyo

7.5a: Pig biological and trade parameters

Parameter	Rates	Unit
Litter size	8	Piglets/farrowing
Farrowing rate	2	Farrowing/pig/year
Time to grow to become weaners	5.5	Weeks
Time weaners fatten to become adults	16	Weeks
Feeding time (Time matures pigs take before traders/butchers buy)	1	Week
Average number pigs sold	200	1/Week
Fraction adult pig sales to DRC/SS traders	0.6	Fraction
Fraction adult pig sales to Moyo traders	0.4	Fraction
Average number of pig slaughters in	80	1/Week
Average carcass weight	30	Kg
Pig to carcass conversion ratio	0.65	Fraction
Pork sales rate	1	Week

7.5b: Farmers cost of feeding pigs

Items	UGX	Total cost per week (Ug Shs)
Feeding	Ug Shs 650 per pig per day	4,440
Feeds transportation	Ug Shs 10,000 per month	2,308

7.5c: Traders' cost of business transaction

Items	Rates in Ug. Shs	Total cost per week (Ug Shs)
Transport per pig	Ug Shs 20,000 per pig x 4 days per week	80,000
Pig slaughter fee	Ug Shs 10,000 per pig daily	70,000
Renting pork-joint premise per month	Ug Shs 120,000 per month=1,440,000 per month	27,692
Cassava (pork accompaniment) per day	Ug Shs 15,000 per day	105,000
Onion (pork accompaniment) per day	Ug Shs 12,000 per day	84,000
Tomatoes (pork accompaniment) per day	Ug Shs 20,00 per day	140,000
Cabbage (pork accompaniment)_daily	Ug Shs 3,000 per day	21,000
Garlic (frying ingredient)_daily	Ug Shs 4,000 per day	28,000
Lemon (frying ingredient)_daily	Ug Shs 3,000 per day	21,000
Salt (frying ingredient)_daily	Ug Shs 3,000 per day	21,000
Red pepper (frying ingredient)_daily	Ug Shs 3,000 per day	21,000
Ginger (frying ingredient)_daily	Ug Shs 3,000 per day	21,000
Firewood daily	Ug Shs 10,000 per day	70,000
Workers payment or labour fee	Ug Shs 130,000 per person per month=1,560,000 per annum	30,000

7.5d: Farmers' cost of farm biosecurity

Items	Unit cost UGX	Total cost per week (Ug Shs)
Constructing pigsty to confine pigs	Ug Shs 2,000,000 for 5 years=400,000 per annum	7,692.31
Veterinary treatment service	Ug Shs 20,000 per annum	384.62
Buying dewormer	Ug Shs 25,000 per annum	480.77
Payment of one worker	Ug Shs 80,000 per month	18,461.54
An overall	Ug Shs 50,000 per annum	961.54
Two pairs of gumboots	Ug Shs 40,000 per annum	769.23
Wheelbarrow for routine manure removal	Ug Shs 150,000 for 3 years	961.54
Spade for routine manure removal	Ug Shs 12,000 per annum	230.77
Brush/Broom for routine cleaning	Ug Shs 7,000 per month=84,000 per annum	1,615.38
Basin (improvised footbath)	Ug Shs 10,000 per annum	192.31
Hand washing facility: 20Ltrs container	Ug Shs 45,000 for 3 years = 15,000 per annum	288.46
Water Jerrican (20Ltr) for fetching water	Ug Shs 14,500 per annum	278.85
Water (dilution of chemicals, & cleaning)	Ug Shs 10,000 per month=120,000 per annum	2,307.69
Disinfectant_1Ltr	Ug Shs 10,000 per month=120,000 per annum	2,307.69
Detergent: 2Ltrs of liquid soap	Ug Shs 4,000 per month=48,000 per annum	923.08

57e: Traders' biosecurity cost

Items	Unit Cost UGX	Total cost per week (Ug Shs)
Gumboots for abattoir work & buying pigs (2 pairs)	Ug Shs 40,000 per annum	769.23
Veterinary movement permit per pig	Ug Shs 3,000 per pig x 4 days per week	12,000
LC1 letter per pig from place of origin	Ug Shs 3,000 per pig x 4 days per week	12,000
Carcass inspection fee per pig	Ug Shs 10,000 per pig daily	70,000
Hand washing facility at pork joint	Ug Shs 45,000 for 3 years=15,000 per annum	288.46
Detergent: 5Ltrs of liquid soap	Ug Shs 10,000 per month=120,000 per year	2,307.69
Water for hand washing hands at pork joint	Ug Shs 5,000 per month = 60,000 per annum	1,153.85
Workers payment at abattoir	Ug Shs 150,000 per month=1,800,000 per annum	34,615.36
Construction of pig holding house	Ug Shs 1,200,000 for 5 years=240,000 per annum	4,615.38

7.5f: Initial cost of pigs and pork

Parameters	Farmers selling pigs to traders		Traders selling pork to consumers	
	Local traders	Foreign traders	Raw pork	Roasted pork
Cost per pig (Ug. Shs)	350,000	500,000	-	-
Cost per Kg (Ug. Shs)	-	-	14,000	27,000

Appendix 7.6 Complete integrated module structure for production and marketing sides

