Veterinary Herd Health Management in Ugandan smallholder pig farms

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Abstract

Animal health research often focus on single, specific diseases such as *e.g.* African swine fever. However, animal health usually depends on multiple factors. In the present thesis, the overall herd health and productivity in 20 smallholder pig farms were assessed by the use of veterinary herd health management, an iterative approach using both interviews, observations, clinical examinations and targeted sampling to obtain a holistic view on the herd. Further, certain problems were identified that likely affected many herds, and the presence of ecto- and endoparasites, parvoviral antibodies, and antibiotic resistance of *Staphylococcus* spp. and *E. coli*, were screened for in all herds.

The main constraints to the production were identified as inadequate feeding, poor reproduction, poor biosecurity, and infectious diseases, although the problems varied considerably among the herds. Low quantity and quality of feed and water caused poor growth rates and poor health, and contributed to increased mortality rates. Suboptimal management was likely one of the main causes of the poor reproductive performance, but pathogens, inadequate nutrition, heat stress, low parity numbers, and inferior breeds probably also contributed to the poor results. Parasites were very common, and apart from pruritus, mainly caused by lice, endoparasites were the most commonly identified cause of clinical disease. In herds of all sizes, coccidia and nematodes caused diarrhea in suckling piglets and growing pigs, resulting in emaciation and even deaths. The two largest herds experienced post-weaning diarrhea associated with enterotoxigenic *E. coli*, resistant to tetracycline that was commonly used to treat the disease. Methicillin-resistant *Staphylococcus aureus* was found in a healthy pig in one herd. African swine fever was not diagnosed, but differential diagnoses such as *Erysipelothrix* infection were suspected. Despite the lack of vaccination programs, parvoviral antibodies were commonly found and parvovirus was thus suspected to be the cause of the high number of mummified fetuses in two herds, and possibly associated with the small litters in several herds.

In conclusion, many different factors affect the health and productivity of smallholder pig herds in Uganda. Efforts to improve health and productivity need to take into consideration both the smallholder context and the situation of the individual herd, as the conditions and motivations differ from those in intensive farms in high-income countries.

Keywords: ETEC, disease, growth, parasites, parvovirus, performance, productivity, reproduction

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Besättningshälsovård i småskaliga grisbesättningar i Uganda

Sammanfattning

Djurhälsa beror av många olika faktorer, men forskning inom området fokuserar ofta på enskilda, specifika sjukdomar som t.ex. afrikansk svinpest. I denna avhandling utvärderades det generella hälsoläget och produktiviteten hos 20 småskaliga grisgårdar med hjälp av besättningshälsovård, en iterativ metod där både intervjuer, observationer, kliniska undersökningar och riktad provtagning används för att få en holistisk bild av hälsoläget i besättningarna. Vidare identifierades problem som sannolikt påverkade många besättningar, och därför undersöktes förekomsten av ekto- och endoparasiter, antikroppar mot parvovirus och antibiotikaresistens hos *Staphylococcus* spp. och *E. coli* i alla besättningar.

Undermålig utfodring, dålig reproduktion, dålig biosäkerhet och infektionssjukdomar identifierades som de främsta begränsningarna i produktionen, men med stor variation mellan besättningarna. Låg kvalité och kvantitet på foder och vatten resulterade i dålig tillväxt och hälsa, och bidrog till en ökad dödlighet. Brister i skötseln var sannolikt en viktig orsak till de svaga reproduktionsresultaten, men patogener, undermålig utfodring, värmestress, unga djur och genetiska faktorer bidrog troligtvis också. Parasiter var vanliga, och förutom klåda orsakad av framför allt löss var endoparasiter den vanligast identifierade orsaken till klinisk sjukdom. Koccidier och nematoder orsakade diarré hos smågrisar och växande grisar i besättningar av alla storlekar, och resulterade i avmagring och även dödsfall. De två största gårdarna hade problem med avvänjningsdiarré associerad med enterotoxisk *E. coli* som var resistent mot tetracyklin, som ofta användes för att behandla sjukdomen. Meticillin-resistent *Staphylococcus aureus* hittades hos en frisk gris i en besättning. Afrikansk svinpest kunde inte påvisas, men differentialdiagnoser som rödsjuka misstänktes i vissa fall. Trots avsaknaden av vaccination så hittades antikroppar mot parvovirus i en tredjedel av besättningarna och denna infektion misstänktes därför vara orsaken till de mumifierade fostren i två besättningar, och möjligtvis associerad till de generellt små kullarna.

Sammanfattningsvis finns det flera faktorer som påverkar hälsa och produktivitet i de småskaliga grisbesättningarna i Uganda. För att förbättra hälsa och produktivitet måste därför både den övergripande kontexten och den enskilda besättningens förutsättningar hållas i åtanke, eftersom situationen och drivkrafterna skiljer sig från gårdar med intensiv produktion i höginkomstländer.

Nyckelord: ETEC, tillväxt, parasiter, parvovirus, produktivitet, reproduktion, sjukdom

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Dedication

Till min far

Sometime there is always yoghurt, and sometimes there is always milk.
Mehdi

Contents

List of publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Gertzell, E.*, Magnusson, U., Ikwap, K., Dione, M., Lindström L., Eliasson-Selling, L., Jacobson, M. (2020). Animal health beyond the single disease approach – a role for Veterinary Herd Health Management in low-income countries? (submitted to *Research in Veterinary Science*)

II Gertzell, E., Ikwap, K.*, Dahlin, L., Selling, K., Hansson, I., Magnusson, U., Dione, M., Jacobson, M. (2020). Presence of antibiotic-resistant *Staphylococcus* spp. and *Escherichia coli* in smallholder pig farms in Uganda (submitted to *BMC Veterinary Research*)

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Abbreviations

ADG – Average daily gain
AMR – Antimicrobial resistance
ASF – African swine fever
ECOFF – Epidemiological cut-off value
EPG – Eggs per gram
ETEC – Enterotoxigenic *Escherichia coli*
HS – Heat stress
MDR – Multi-drug resistance/resistant
MIC – Minimum inhibitory concentration
MRSA – Methicillin-resistant *Staphylococcus aureus*
OPG – Oocysts per gram
PCV-2 – Porcine circovirus type 2
PED – Porcine epidemic diarrhea
PPV – Porcine parvovirus
PRRS – Porcine reproductive and respiratory syndrome
PWD – Post-weaning diarrhea
TGE – Transmissible gastroenteritis
VHHM – Veterinary herd health management
WI – Wealth index

1 Background

Livestock is of great importance for the poor (Oosting *et al.*, 2014; Herrero *et al.*, 2013; Randolph *et al.*, 2007), especially in the rural areas where the majority of the people in sub-Saharan Africa live (World Bank, 2020). Food-producing animals do not only generate an income for the smallholder farmers, they also function as “banks”, provide food, manure and traction power, and increase the social status (Randolph *et al.*, 2007). Thus, livestock can be directly and indirectly linked to several of the United Nations sustainable development goals (UN, 2015). Livestock productivity is a very important aspect in poverty reduction in low-income countries (Pradere, 2014), and often drives increases in gross domestic product (Pica *et al.*, 2008). The productivity of animals in smallholder farms is generally low, and productivity is closely related to animal health (Kruse *et al.*, 2019; Friendship & O'Sullivan, 2015; Jørgensen, 1992). In practice, animal health is often multifactorial, however, 95% of the research on infectious animal health is done on single pathogens (Ducrot *et al.*, 2016).

This thesis thus aimed at investigating pig health in a low-income country using a holistic approach, *i.e.* veterinary herd health management.

1.1 Uganda

Uganda is a low-income country (Development Assistance Committe, 2019) with a population of 42.7 million people (World Bank, 2020), situated on the equator in East Africa. It is a beautiful country with fertile land and a warm and generally wet climate, though scarred by years of previous conflicts, especially in the northern parts (Briggs & Roberts, 2010).

Administratively, Uganda is divided into four regions; Central, Western, Eastern and Northern, with an increasing number of districts (127 districts as of July 2018), each comprising several sub-counties (Ministry of Local Government, 2018). A sub-county is further divided into many parishes, which in turn comprises a number of villages. The work in this thesis was conducted in the Lira district, a part of the Lango sub-region, situated in the Northern region of Uganda.

According to the World Bank (2020), 76% of the Ugandan population live in rural areas and 70% work with agriculture. An equally large proportion of the population keep livestock, mainly tended to by family labor (MAAIF-UBOS, 2009). Both the actual number and the percentage of Ugandans living in poverty have increased in recent years, from 19.5% of the population in 2012/2013 to 27% in 2016/2017 (UBOS, 2017). In the Lango sub-region, the majority state that their living conditions have worsened during the same time period (UBOS, 2017).

1.2 Pig production in Uganda

There are several theories on the origin of the East African pigs. East Africans are not believed to have been keeping pigs before the species was introduced by the Europeans, but it is disputed whether this occurred during the 19th century or if pigs were introduced earlier by seafarers (Noce *et al.*, 2015; Blench, 2000). The local, indigenous pigs are small, black or spotted with a straight tail and semi-erect, medium-sized ears (Blench, 2000). Nowadays, Ugandans keep both local and "exotic" pig breeds, such as *e.g.* Large White or Landrace (Muhanguzi *et al.*, 2012; Biryomumaisho & Ogalo, 2007), and crosses between these are common (Ikwap *et al.*, 2014b).

Uganda has one of the largest pig populations in Africa, estimated to be between 2.6 million and 3.2 million heads (FAOSTAT, 2019a; MAAIF-UBOS, 2009). They are an increasingly popular livestock, with a ten-fold rise over the last 30 years (FAOSTAT, 2019b) and an anticipated increase in the number of animals of almost 200% until 2050 (Wisser *et al.*, 2018). The produced amount of pork is projected to rise even further due to an increased productivity (Wisser *et al.*, 2018). Eighteen percent of the households keep pigs (MAAIF-UBOS, 2009) but still, some claim that the species has not been prioritized by the government (Ouma *et al.*, 2015).

In many aspects, the smallholder pig production in Uganda is similar to that in other sub-Saharan countries, such as Botswana (Nsoso *et al.*, 2006), Cameroon (Kouam *et al.*, 2020; Ndebi *et al.*, 2009), Kenya (Mbuthia *et al.*, 2015; Mutua *et al.*, 2011a; Kagira *et al.*, 2010), Nigeria (Chah *et al.*, 2014), South Africa (Munzhelele *et al.*, 2017), Tanzania (Braae *et al.*, 2016; Mbaga *et al.*, 2005) and Zimbabwe (Chiduwa *et al.*, 2008). Most Ugandan pig farmers are smallholders, keeping less than five pigs (Ndyomugyenyi & Kyasimire, 2015; Nissen *et al.*, 2011; MAAIF-UBOS, 2009), and either produce piglets, keep growers for fattening or have integrated herds (Ouma *et al.*, 2014). Pigs are mainly kept as a source of income or as financial assets that can be sold at any time to *e.g.* pay for school fees (Roesel *et al.*, 2019; Baker *et al.*, 2015; Ouma *et al.*, 2015; Muhanguzi *et al.*, 2012; Ampaire & Rothschild, 2010), but also for manure production (Baker *et al.*, 2015). Many farmers keep their pigs on a very low input system (Chenais *et al.*, 2017a), and the pigs are seldom consumed by the household themselves (Dione *et al.*, 2014b; Muhanguzi *et al.*, 2012). Women generally take daily care of the pigs (Baker *et al.*, 2015; Ikwap *et al.*, 2014b), but they do not always have access to the income the pigs generate (Carter *et al.*, 2017b).

The pigs are kept either on free-range, tethered, confined or in a mixture of these systems (Fig. 1; Ndyomugyenyi & Kyasimire, 2015; Dione *et al.*, 2014b; Ikwap *et al.*, 2014b; Ouma *et al.*, 2014; Muhanguzi *et al.*, 2012). If present, confinements are built with locally available material, such as bricks, clay or wood, and may or may not have a constructed floor and roof (Dione *et al.*, 2014b). The pens are sometimes poorly built which allow pigs to escape (Muhanguzi *et al.*, 2012). Confining pigs is more common in urban areas, while tethering is the most common way of keeping pigs in rural areas (Dione *et al.*, 2014b). It is also common that farmers, who keep their pigs confined, let them out to be free-ranging for some parts of the day (Muhanguzi *et al.*, 2012).

Disease and input constraints are the most frequently mentioned major constraints to the pig producers in Uganda (Baker *et al.*, 2015; Ndyomugyenyi & Kyasimire, 2015; Dione *et al.*, 2014b; Ouma *et al.*, 2014; Muhanguzi *et al.*, 2012). The input constraints are mainly associated with the lack of and/or poor quality of feed and water, and poor quality and/or expensive advisory veterinary services and drugs. Lack of capital is often mentioned in relation to the input constraints (Baker *et al.*, 2015; Muhanguzi *et al.*, 2012). Further, the farmers themselves, especially in rural areas, think that they lack knowledge on proper management (Dione *et al.*, 2014b), and this might be a more important constraint than the lack of capital (Baker *et al.*, 2015). Poorly organized markets are another described constraint (Ouma *et al.*, 2014; Muhanguzi *et al.*, 2012).

1.2.1 Routine management

Different routine management practices are performed to a various extent, and many farmers perform routine medical treatments (see below). While some authors report that most pig farmers keep records (Kabuuka *et al.*, 2014), others find that records are generally not used (Chenais *et al.*, 2017a; Dione *et al.*, 2017), or identify poor record keeping as a constraint (Muhanguzi *et al.*, 2012). It has been suggested that most farmers castrate their male pigs at the age of two weeks (Dione *et al.*, 2014b; Ouma *et al.*, 2014). On the contrary, a study from Kenya found that castration was mainly performed after the age of 4 weeks (Kagira *et al.*, 2010). Castration is most often performed by a hired person, and not by the farmers themselves (Dione *et al.*, 2014b). Teeth cutting is not a common practice (Dione *et al.*, 2014b; Biryomumaisho & Ogalo, 2007). Administration of iron is generally not routinely performed, instead some farmers let their pigs scavenge in order to ingest red soil as an iron booster (Dione *et al.*, 2014b). As previously stated, farmers themselves regard lack of knowledge on management practices as a limitation to the animal health (Dione *et al.*, 2014b).

Figure 1. Different rearing conditions in Lira, Uganda. Author's photographs

1.2.2 Feeding and growth

Most farmers use home-grown or home-made feed stuffs like maize bran, cassava, brew waste, potatoes, swill, forage or other crop residues, while commercial feed formulations are rare (Ndyomugyenyi & Kyasimire, 2015; Ikwap *et al.*, 2014b; Muhanguzi *et al.*, 2012). It is rare that the farmers feed their pigs *ad lib* (Muhanguzi *et al.*, 2012) and both water and feed are commonly given once or twice per day (Ndyomugyenyi & Kyasimire, 2015; Muhanguzi *et al.*, 2012).

The average daily gains (ADG) in smallholder settings in sub-Saharan Africa have been found to be low, estimated to approximately 50-200 g/day (Lipendele *et al.*, 2015; Carter *et al.*, 2013; Mutua *et al.*, 2012; Wabacha *et al.*, 2004), and malnutrition has been identified by many Ugandan farmers as a health constraint (Dione *et al.*, 2014b). For example, pigs in Tanzania have been found to receive too little water (Braae *et al.*, 2016) and pigs in Nigeria have been given diets with a high fibre content but deficient of both energy and nutrients, *e.g.* proteins (Abonyi *et al.*, 2012).

1.2.3 Reproduction

Natural breeding is almost exclusively practiced (Ikwap *et al.*, 2014b). Many farmers use village boars (a boar borrowed from someone in the neighborhood) to serve their sows, and pay for the service with cash or with a piglet (Dione *et al.*, 2014b; Ikwap *et al.*, 2014b). Most sows give birth to 6-10 piglets, but it is not uncommon with smaller litters (Ikwap *et al.*, 2014b; Muhanguzi *et al.*, 2012), and sows in backyard herds seem to farrow slightly fewer piglets than those kept in intensive herds (Biryomumaisho & Ogalo, 2007). One study found that almost one-third of the piglets died before weaning, mostly from crushing or starvation (Biryomumaisho & Ogalo, 2007). The average number of parities per sow seems to be low (Ikwap *et al.*, 2014b), and one study from the central region found that very few farmers used their own gilts for replacement (Muhanguzi *et al.*, 2012). Weaning have been described to occur above two months of age, usually by removal of the sow (Ikwap *et al.*, 2016).

1.2.4 Selling and slaughtering

Pigs are usually sold in small numbers a few times per year (Ouma *et al.*, 2017), mainly to traders (Atherstone *et al.*, 2019), but sometimes also directly to butchers (Ouma *et al.*, 2014). Pig traders travel from farm to farm to buy pigs, mainly for slaughter, and pig farmers generally have competing traders to sell to (Atherstone *et al.*, 2019). In the negotiation of the price for a pig, health status and body condition, more so than *e.g.* breed or age, are important pig-related factors (Atherstone *et al.*, 2019; Ndyomugyenyi & Kyasimire, 2015). Non-pig related factors associated to higher prices are holidays and harvesting season, while lower prices are related to periods when school fees are due (Atherstone *et al.*, 2019). Drought may, depending on the current market, result in both higher or lower prices. Except Wambizzi in Kampala, the only official pig slaughter house, Uganda lacks official and controlled pig abattoirs, which results in unregulated backyard slaughter (Ouma *et al.*, 2017), generally without veterinary inspections (Muhangi *et al.*, 2014). Traders supplying pigs to the Wambizzi abattoir, buying pigs all over the country, prefer buying pigs from men over women because they are believed to be the final decision maker and the owner of the pigs (Atherstone *et al.*, 2019). However, women are the decision-makers in a fourth of the households in some parts of the country (Ikwap *et al.*, 2014b).

1.2.5 Biosecurity

Generally, the knowledge and practice of biosecurity is low (Nantima *et al.*, 2016), and the practice of "all in-all out" is uncommon (Kabuuka *et al.*, 2014). Even when biosecurity protocols exist, they are not always upheld. Chenais *et al.* (2017c) described how non-compliance with the protocols potentiated the spread of African swine fever (ASF) on a medium-sized farm. In one study, the use of a quarantine was reported by more than half of the farmers (Muhanguzi *et al.*, 2012), while others found that almost none used a quarantine for the incoming pigs (Nantima *et al.*, 2016). Boot-baths and disinfectants have been proposed as a measure to improve biosecurity (Dione *et al.*, 2016; Muhangi *et al.*, 2014), but studies suggest that they are not always used properly (Chenais *et al.*, 2017c; Kabuuka *et al.*, 2014). Even if farmers themselves believe that disease control measures are effective, these can be hard to implement, due to lack of money and capacity (Dione *et al.*, 2016; Nantima *et al.*, 2016).

The use of village boars has been discussed as a biosecurity risk (Dione *et al.*, 2016; Ndyomugyenyi & Kyasimire, 2015; Ikwap *et al.*, 2014b; Muhangi *et al.*, 2014). Other practices that imply biosecurity risks are *e.g.* not confining the pigs, buying animals with unknown disease status, and the free access to the pigs by visitors without any biosecurity protocol (Muhangi *et al.*, 2014).

Further, farmers in Lira claim that other farmers, due to old conflicts, or traders, due to disagreements after price negotiations, deliberately try to transmit ASF by placing remnants from dead pigs near the farm (Dione *et al.*, 2016). This practice has also been reported in other districts by Nantima *et al.* (2016). When an outbreak of ASF occurs, the government can impose a ban on trading or moving pigs within or out of the affected area (Animal Diseases Act, 2000). These restrictions are not always complied with (Muhangi *et al.*, 2014), or even known of, neither by the farmers (Nantima *et al.*, 2016) nor the police officers (Dione *et al.*, 2016).

The sub-optimal practice of biosecurity also applies to the animal health workers who often move from farm to farm without undertaking proper biosecurity measures (Dione *et al.*, 2020; Dione *et al.*, 2016). Traders, delivering to the Wambizzi slaughterhouse and collecting pigs from all over Uganda, claim to clean their vehicles after each use (Atherstone *et al.*, 2019). However, even if the traders observe obvious signs of disease in their pigs, the pigs are still slaughtered and the meat sold (Atherstone *et al.*, 2019).

1.2.6 Veterinary services

Veterinary services are limited in Uganda (Dione *et al.*, 2014b). Although one study from the central region stated that farmers received veterinary service every month (Muhanguzi *et al.*, 2012), other studies found that many farmers did not contact a veterinarian when facing a disease (Dione *et al.*, 2014b; Ikwap *et al.*, 2014b; Muhanguzi *et al.*, 2012), or failed to reach one if needed (Dione *et al.*, 2014b). Men generally have more access to animal health services than women (Ouma *et al.*, 2015). Most people working with animal health services in Uganda are people holding a diploma or certificate in an animal or agriculture-related area ("paraveterinarians"), while only a few hold a university degree in veterinary medicine (Dione *et al.*, 2014a). Animal health workers work mostly with curative treatments, but sometimes also with preventive treatments and advisory services (Dione *et al.*, 2014a). Farmers sometimes claim that paraveterinarians have given their pigs a preventive treatment against ASF (Dione *et al.*, 2016) which may be an injection with antibiotics and multi-vitamins (Dione *et al.*, 2014b).

Medical treatments

Medical treatments are usually given as single doses, either by the farmers themselves, or by a paraveterinarian/veterinarian (Dione *et al.*, 2014b). Many misconceptions regarding treatments exist among the farmers, and sick pigs are often treated without further diagnosis (Dione *et al.*, 2014b).

Most farmers deworm their pigs to achieve faster growth, either once (*e.g.* before selling the pig) or routinely, most commonly every three months (Lagu *et al.*, 2017; Roesel *et al.*, 2017; Ndyomugyenyi & Kyasimire, 2015; Dione *et al.*, 2014b; Ouma *et al.*, 2014). Albendazole and ivermectin are the most commonly used anthelmintic drugs (Roesel *et al.*, 2017; Dione *et al.*, 2014b), but levamisole, praziquantel and piperazine are also used (Dione *et al.*, 2014a). Some farmers also practice parasite spraying with an acaricide against ectoparasites (Dione *et al.*, 2014b). Other drug treatments applied by a few farmers include multi-vitamin and iron injections (Dione *et al.*, 2014b; Ouma *et al.*, 2014; Biryomumaisho & Ogalo, 2007). Multi-vitamin injections are given either as growth promoters to growing pigs, or to pregnant sows (Dione *et al.*, 2014b).

In most herds, antibiotics are not routinely administered, but rather given when the pigs are sick (Dione *et al.*, 2014b). However, other authors state that antibiotic prophylaxis is a common practice in large herds (Okello *et al.*, 2015). Tetracycline is the most commonly used antibiotic in livestock in Uganda, followed by penicillin solely or combined with streptomycin, and sulfonamides with or without trimethoprim (Okubo *et al.*, 2019).

Apart from the conventional drugs, some farmers treat sick pigs suffering from suspected ASF with local herbs or urine (Dione *et al.*, 2014b). Vaccination of pig diseases is not reported in Uganda (Dione *et al.*, 2018), and the lack of prophylaxis programs has been mentioned by farmers as a health constraint (Dione *et al.*, 2014b).

1.2.7 Pathogens

Pig farmers perceive diseases as a major constraint to their production (Ndyomugyenyi & Kyasimire, 2015; Dione *et al.*, 2014b; Ouma *et al.*, 2014; Muhanguzi *et al.*, 2012). African swine fever and parasites are described by farmers and paraveterinarians as the most important and common diseases (Dione *et al.*, 2014a; Dione *et al.*, 2014b; Muhanguzi *et al.*, 2012), but other illnesses, unknown by the farmers, are likely also present (Dione *et al.*, 2014b).

Parasites

Internal parasites are very common in the small-scale pig production in Uganda (Lagu *et al.*, 2017; Roesel *et al.*, 2017; Nissen *et al.*, 2011). Strongyles have most frequently been found, but *e.g.* coccidia, *Metastrongylus* spp., *Ascaris* (*A.*) *suum*, *Strongyloides* (*S.*) *ransomi* and *Trichuris* (*T.*) *suis* have also been identified. High mean or median fecal egg counts (>500 eggs per gram) have been found with respect to strongyles, *A. suum* and *T. suis* (Lagu *et al.*, 2017; Nissen *et al.*, 2011), and *Metastrongylus* spp. is very common in slaughtered pigs[1]. Porcine cysticercosis (*Taenia solium*), an important zoonosis, is also common in Uganda, but the occurrence varies with the methods used in the analyses and across the

1. Personal communication, DVM Podpodo Cecil, District Veterinary Office Lira, 2018

country (Kungu *et al.*, 2017; Zirintunda & Ekou, 2015; Nsadha *et al.*, 2014; Waiswa *et al.*, 2009; Kisakye & Masaba, 2002). *Trichinella* larvae have not been demonstrated, and examination of serum from 1125 pigs from three different districts revealed a seroprevalence of 2.1% (Roesel *et al.*, 2016).

In pig production in other parts of the world, endoparasites may be associated with poor performance (Kipper *et al.*, 2011). In Uganda, internal parasites are hypothesized to be related to poor average daily weight gain and feed conversion ratios (Roesel *et al.*, 2017), and both endo- and ectoparasites are believed by the farmers to cause stunted growth (Dione *et al.*, 2014b).

Ectoparasites, such as lice, fleas and mange (*Sarcoptes* (*S.*) *scabiei*) are commonly described by farmers as an animal health problem (Dione *et al.*, 2014b), but, apart from the sand flea *Tunga penetrans*, no study have been done on their presence or clinical importance in Uganda. The sand flea is a zoonosis, and the clinical signs are related to the female fleas burying in the skin, causing *e.g.* inflammation, pain, pruritus, and secondary infections, mainly on the feet, in humans (Feldmeier *et al.*, 2004). In pigs, the flea has been described to cause severe clinical disease, presenting as *e.g.* edema, ulcers/erosions, necrosis, lameness, pain, pruritus and dermatitis, mainly on the legs and feet (Mutebi *et al.*, 2017; Mutebi *et al.*, 2016). Despite obvious clinical signs, the disease is often neglected in both humans and livestock, and many farmers and animal health workers are not aware of the disease (Mutebi *et al.*, 2017; Feldmeier *et al.*, 2014).

African swine fever

African swine fever is a severe hemorrhagic disease caused by a member of the *Asfariviridae* family, the ASF virus. The disease is endemic in Uganda and estimates of the yearly incidence on farm level varies considerably up to 33% (Chenais *et al.*, 2017a; Dione *et al.*, 2017; Chenais *et al.*, 2015; Muhangi *et al.*, 2015; Muhangi *et al.*, 2014). Outbreaks seem to be somewhat seasonal, more often occurring during the dry season and festive periods (Chenais *et al.*, 2017b; Dione *et al.*, 2014b). The clinical signs of acute ASF include fever, inappetence, apathy and skin erythema, and the mortality may reach up to 100% (Sánchez-Vizcaíno *et al.*, 2015), but is assessed by Ugandan farmers to generally be lower (Muhangi *et al.*, 2015; Dione *et al.*, 2014b).

Other diseases and pathogens

Diarrhea is another health issue that is frequently described by the farmers (Dione *et al.*, 2017; Ikwap *et al.*, 2016; Dione *et al.*, 2014b; Ikwap *et al.*, 2014b). In one study, 38% of the responding herds stated that they had a problem with diarrhea in the pigs, especially in suckling piglets more than one week of age

(Ikwap *et al.*, 2014b), though the cause have not been investigated. Post-weaning diarrhea, due to enterotoxigenic *E. coli* (ETEC), has been described in both commercial and smallholder pig farms in Uganda (Ikwap *et al.*, 2016; Okello *et al.*, 2015). Strains carrying the fimbrial genes F18 and F4, together with heat stable toxins (STa and STb) seems to be most commonly present (Ikwap *et al.*, 2016; Okello *et al.*, 2015). *Salmonella* spp. have been found in diarrheic pigs (Ikwap *et al.*, 2014a), as well as isolated from presumably healthy pigs at slaughter (Afema *et al.*, 2016; Tinega *et al.*, 2016). Rotavirus type A and type C have been found in the feces of apparently healthy pigs (Amimo *et al.*, 2017; Amimo *et al.*, 2015).

Coughing is commonly described by the farmers (Dione *et al.*, 2017; Ikwap *et al.*, 2014b), but has not been studied further. Studies on respiratory diseases in pigs are generally lacking in Africa (Oba *et al.*, 2020).

A serological survey of several pig pathogens in two Ugandan districts detected antibodies to *Streptococcus suis* (70.3%), porcine circovirus type 2 (PCV-2; 45.2%), *Actinobacillus pleuropneumoniae* (22.8%), *Mycoplasma hyopneumoniae* (14.9%), swine influenza virus (5.0%), porcine parvovirus (PPV; 5.0%), porcine reproductive and respiratory syndrome virus (PRRS; 1.5%), rotavirus (0.8%) and Aujeszky's disease virus (0.2%; Dione *et al.*, 2018). In another study on 239 samples, PRRS was neither detected by PCR nor by serology (Muhangi *et al.*, 2015). Antibodies to *Erysipelotrix* (*E.*) *rhusiopathiae* and the bacteria itself have been detected in blood and meat samples respectively, from slaughtered, presumably healthy, pigs (Musewa *et al.*, 2018). Porcine circovirus type 2 have been found in a few pigs by immunohistochemistry and PCR, both in association with chronic emaciation (Wilfred *et al.*, 2018) and in presumably healthy pigs at slaughter (Ojok *et al.*, 2013). Foot-and-mouth disease have been mentioned by the farmers (Dione *et al.*, 2014b), but the presence has not been investigated in pigs. Classical swine fever has not been reported from Uganda (OIE, 2020), and neither the virus, nor antibodies to it, were found in a study investigating differential diagnoses to ASF (Muhangi *et al.*, 2015).

While animal health workers quote brucellosis as the most common zoonosis in pigs (Dione *et al.*, 2014a), results from both serology and PCR have failed to demonstrate the presence of the disease among pigs in Uganda (Erume *et al.*, 2016). Different *Mycobacterium* (*M.*) spp., both *M. bovis* and non-tuberculous mycobacteria, have been found in lymph nodes from healthy pigs at slaughter (Muwonge *et al.*, 2012a; Muwonge *et al.*, 2012b; Muwonge *et al.*, 2010).

Further, different miscellaneous viruses have been found by molecular biology methods in pigs in Uganda, but the association to clinical disease is unclear. These include kobuviruses, astroviruses (Amimo *et al.*, 2014), bocaviruses (Blomstrom *et al.*, 2013), Torque teno viruses, and Ndumu virus (Masembe *et al.*, 2012).

1.2.8 Heat stress

As pigs have limited ability to sweat, they are prone to heat stress (HS), presenting as elevated rectal temperatures and increased respiratory rates (Pearce *et al.*, 2013a; Quiniou & Noblet, 1999; Wettemann *et al.*, 1976). The high temperatures and humidity in northern Uganda commonly results in conditions indicative of heat stress in pigs (Mutua *et al.*, 2020). Further, HS may be aggravated as some farmers do not provide water for their pigs (Muhanguzi *et al.*, 2012) or confine the pigs without a roof as shade (Dione *et al.*, 2014b). On the other hand, the situation may be improved by the provision of mud baths, as some farmers do (Dione *et al.*, 2014b).

Heat stress may result in reduced feed intake and, consequently, reduced milk production in lactating sows, leading to poorer piglet growth and body weights (Quiniou & Noblet, 1999). Reproductive performance is affected in both boars and sows. Boars suffering from HS have compromised sperm quality, and reduced fertilization and embryonic survival rates (Wettemann *et al.*, 1976). Sows exposed to increased temperatures have more stillborn piglets, reduced litter sizes, and poorer farrowing rates (Wegner *et al.*, 2016; Bloemhof *et al.*, 2013), an effect that is more evident in gilts (Bloemhof *et al.*, 2013). The timing of the HS in relation to reproductive events seems to be important. Growing pigs with HS have a compromised intestinal integrity, making the intestines more permeable to endotoxins, possibly partly due to the decreased feed intake (Pearce *et al.*, 2013a; Pearce *et al.*, 2013b). Elevated environmental temperatures have also been associated with higher mortality in sows (D'Allaire *et al.*, 1996), due to cardiac failure (Drolet *et al.*, 1992).

1.3 Antimicrobial resistance

Antimicrobial resistance (AMR) refers to the resistance of microorganisms to drugs used to treat their infections. The World Health Organization identifies AMR as a threat to "the very core of modern medicine" (WHO, 2015). Both human health and economy, as well as animal health and food production, are threatened when treatment options are reduced (WHO, 2015; Bengtsson & Greko, 2014).

Development of antibiotic resistance may occur either through mutations in the individual bacteria, or may be horizontally transferred between bacteria, *e.g.* through mobile genetic elements such as plasmids or transposons (Munita &

Arias, 2016). The resistance mechanisms vary between bacteria, but include *e.g.* modifying the antibiotic drug, modifying the target of the antibiotic substance, reducing the uptake, or increasing the efflux of the antibiotic substance.

One of the cornerstones in combating AMR is surveillance, but data on the occurrence of AMR in both humans (Tadesse *et al.*, 2017) and animals (Van Boeckel *et al.*, 2019) in Africa is scarce. Likewise, Uganda lack a national AMR surveillance program (UNAS *et al.*, 2015).

1.3.1 *Staphylococcus* spp.

Investigations on the occurrence of AMR in *Staphylococcus* (*S.*) spp., mainly *S. aureus* and especially methicillin-resistant *S. aureus* (MRSA), isolated from both healthy and diseased animals, may be included in surveillance programs of AMR (Schrijver *et al.*, 2018; WHO, 2017). Methicillin-resistant *S. aureus* produce penicillin-binding proteins, encoded for by the genes *mecA* or *mecC*, and thus have reduced susceptibility to most β-lactams. It is one of the most common antibiotic-resistant pathogens globally. Further, the *mecA* and *mecC* genes may be transferred to other bacteria through mobile genetic elements called staphylococcal cassette chromosomes *mec* (SCC*mec*), and these might also include genes expressing resistance to other antibiotics such as tetracycline or erythromycin (Reygaert, 2013). In the beginning of the century, MRSA was not believed to be of zoonotic importance (Bywater, 2004). This view have since changed, and currently, livestock-associated MRSA is considered to be of importance especially to people with occupational contact with livestock, and their close relations (Becker *et al.*, 2017; Goerge *et al.*, 2017; Oppliger *et al.*, 2012; Voss *et al.*, 2005).

In Uganda, the presence of MRSA has been studied mainly in humans, generally revealing an occurrence of <10% (*e.g.* Abimana *et al.*, 2019; Kateete *et al.*, 2019; Bebell *et al.*, 2017). Studies of MRSA in animals are scarce and MRSA have been found in milk (Asiimwe *et al.*, 2017), but not in cattle (Wachtmeister, 2018). To the author's knowledge, no studies on MRSA in pigs in Uganda have been scientifically published. However, one study published at Makerere University, that has not been possible to retrieve but have been cited by others, reported an occurrence of 64% (Kalule *et al.*, 2014, in UNAS *et al.*, 2015). Another study, published in a journal not indexed in Web of Science or PubMed, and not a member the Directory of Open Access Journals or the Committee of Publication Ethics, reported a 29.4% occurrence of MRSA in pigs in south-western Uganda (Baguma *et al.*, 2018). In other African countries, MRSA in pigs have *e.g.* been studied and found in Nigeria (Adesida *et al.*, 2019; Odetokun *et al.*, 2018; Otalu *et al.*, 2018), Senegal (Fall *et al.*, 2012), and South

Africa (Van Lochem *et al.*, 2018; Adegoke & Okoh, 2014), but was not found in Tanzania (Katakweba *et al.*, 2016). The methods used in the analyses differ between the studies and some authors do not report MRSA isolated from pigs separately, but when data is shown, the occurrence has generally been fairly low (<10%).

1.3.2 *E. coli*

Escherichia coli are commensal bacteria found in the intestinal tract of animals and humans, and are often used as indicator bacteria to *e.g.* monitor AMR (EFSA *et al.*, 2019; WHO, 2017). The bacteria are generally apathogenic, but certain strains, *e.g.* ETEC and enterohemorrhagic *E. coli* (EHEC), may cause severe clinical disease in both animals and humans. Further, as previously mentioned, resistance genes in *E. coli* might also be horizontally transferred to other, pathogenic, bacteria. For example, resistance to several classes of antibiotics such as β-lactams (*bla*-genes), tetracycline *(tet*-genes) or aminoglycosides (*aac*/*ant*/*aph*-genes) may be transferred though plasmids, while single point mutations are more common causes of trimethoprim/sulfonamide resistance (Reygaert, 2017).

Antibiotic resistant isolates of *E. coli* from healthy pigs are common globally, though the levels vary considerably between countries (EFSA & ECDC, 2019; Katakweba *et al.*, 2018; Strom *et al.*, 2018; Lei *et al.*, 2010). Two studies have reported antimicrobial resistance patterns of *E. coli* in pigs in Uganda. One study on apparently healthy animals revealed that resistance was widespread, especially to tetracycline (97.5%), and found multi-drug resistance (MDR) in 15% of the pigs (Okubo *et al.*, 2019). In the other study, performed on clinical isolates from presumed *E. coli*-associated diarrhea, all isolates were MDR and in general, high levels of resistance was found (Okello *et al.*, 2015).

2 Aim

The overall aim of this project was to investigate the herd health and associated management and productivity factors in smallholder pig farms in Uganda by the application of a holistic and iterative approach, *i.e.* veterinary herd health management (VHHM).

The specific aims were

- To identify and generate in-depth knowledge on health and productivity constraints in smallholder pig farms in Uganda using VHHM (study I)

- To investigate the presence and antibiotic susceptibility pattern of two commonly studied pathogens, *i.e. Staphylococcus* spp., including MRSA, and *E. coli*, in these herds (study II)

Photo Benard Okello

3 Aspects on materials and methods

This section includes some aspects of the methods used in the two studies in the thesis. For more detailed information regarding the methods, see study I and study II.

3.1 Veterinary herd health management

Regular herd visits with the aim of identifying productivity constraints and improving health are a globally used method in large animal veterinary practice (Ramirez & Karriker, 2019; Derks *et al.*, 2013). Many animal health disorders are multifactorial and might not be captured by laboratory tests only (Enting *et al.*, 1998; Goodwin, 1971). Thus, several authors describe a methodology where systematic discussions with the farmers, observations of *e.g.* pigs, management, feeding, buildings and environment, clinical examinations of pigs, targeted or planned samplings, and review of the production figures, are combined to identify health and productivity constraints (Ramirez & Karriker, 2019; Jorgensen *et al.*, 2002; Enting *et al.*, 1998; Blocks *et al.*, 1994; Basinger, 1985; Becker, 1979; Aalund *et al.*, 1976; Goodwin, 1971). A continuous review of the previously gathered information and close collaboration with the farmers and employees are important features of this process. The herd, and not the individual pig or piglets, is the object of study. Subsequently, the data gathered should be used to continuously improve the identified constraints.

The terminology of such an approach varies from veterinary herd health management (Derks *et al.*, 2013; Blocks *et al.*, 1994) or different combinations of the words herd, health, evaluation, visit and/or program (Ramirez & Karriker, 2019; Enting *et al.*, 1998; Becker, 1979), to preventive medicine (Basinger, 1985; Becker, 1979; Muirhead, 1979; Aalund *et al.*, 1976; Nadeau, 1965) or advisory visits (Muirhead, 1980). In this thesis, the method to identify health and productivity constraints through regular farm visits will be termed veterinary herd health management (VHHM).

3.2 Study design

A list of 250 pig farmers in the study area were generated by the local District Veterinary Office. To enable travel, the study area was determined as the four sub-counties closest to Lira town. Further, to avoid bias in the results, only parishes where no known previous interventions had been conducted, were included. Inclusion criteria were set as herds including at least one sow, to be able to study reproduction, and farmers keeping the pigs confined or tethered, to be able to inspect and examine the pigs at each visit. Thirty-eight pig farmers met the two inclusion criteria and twenty of these were selected by simple randomization. In this context, farms with up to three sows/year were considered "small", as described by Ouma *et al.* (2018), while the other farms were considered "large".

The fieldwork in study I was conducted between July 2018 and June 2019 and in study II, during September 2019.

Veterinary herd health management was applied in study I, with regular herd visits in the selected herds every month; every second month by the author (primary visits) and every other month by either one of two extension workers (secondary visits), who also accompanied the author on all primary visits. On the primary visits, a semi-structured interview was conducted with the farmer or manager, observations were made, pigs were inspected, examined and their size was determined, and targeted sampling was performed. On the secondary visits, a structured interview, structured observations, and sizing of the pigs were performed. Additionally, the farmers received a visitors' log and a record-keeping file, and were asked to record specified events in the pig production, such as entries and exits, deaths, sickness, treatments, heat, service, farrowings, and weaning of the pigs. Before each primary visit, a list of occurring or suspected health and productivity problems in every herd was formulated based on the information gathered at previous visit's and the farmers' records. The list was used to identify areas were more knowledge was needed, and thus to revise and plan the next visit, *e.g.* targeted sampling or new topics to include in the interviews (Fig. 2). This approach might lead to a skewed emphasis on some problems or diseases, as previous experience and knowledge will affect the focus. However, this possible bias was sought to be minimized by the consultation of the supervisors, knowledgeable in practical pig medicine in both Sweden and in Uganda. As in clinical practice, it is neither possible, practical, nor desirable to investigate every conceivable differential diagnosis.

Screenings of pathogens and related issues that were identified by the VHHM as likely to be important to many of the pig producers in Lira were also performed (study I+II). Further, in study II, a structured interview on the antibiotic usage was conducted in September 2019.

Required permissions from the Uganda National Council of Science and Technology, the Uganda Ministry of Agriculture, Animal Industry and Fisheries, the College of Veterinary Medicine, Animal Resources and Biosecurity, Makerere University, and from the Swedish Board of Agriculture were obtained before the research was conducted and the samples were transported to Sweden.

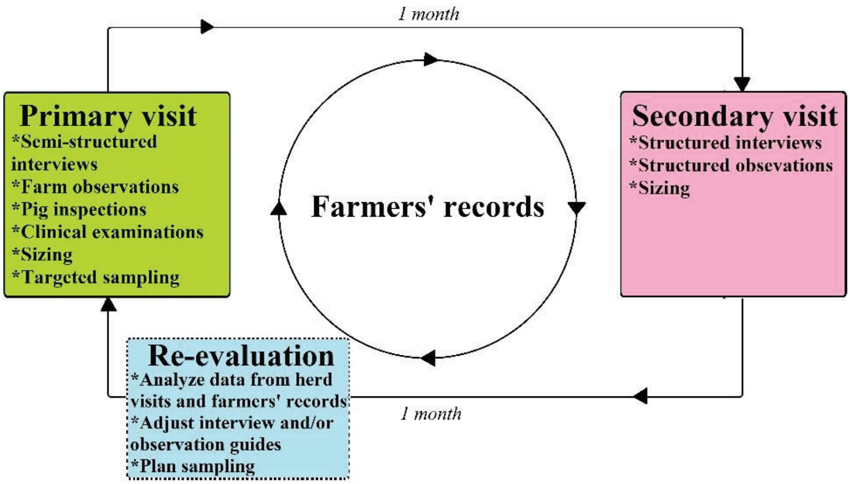

Figure 2. Schematic view of the veterinary herd health management approach.

3.3 Interviews and observations

Semi-structured interview guides were used to be able to retrieve information that were deemed likely to be relevant, and at the same time be flexible and let the farmers address any subject of importance. Open-ended questions were preferably posed. Additionally, the interview guide also included fixed basic questions, such as “Have any of your sows farrowed since the last visit?”, to gather information needed to calculate production figures. Answers regarding health and disease status often had to be probed several times at each visit, since the farmers otherwise tended to report only one or a few issues initially. When statements seemed unlikely, questions were re-formulated and re-posed, or the information was supplemented by *e.g.* observations for triangulation. For example, if a farmer stated that they fed their pigs an unlikely high amount of feed, compared to the body condition and growth of the pigs, information on how much feed they bought each time and how long it lasted was gathered, or the stated daily amount of feed was weighed on a scale. This was however only possible if the farmers used a few, easily quantified, feedstuff such as maize bran or raw cassava, as the amount and availability of other feedstuff such as leftovers varied, and the forage was hard to quantify.

The observation sheet was used as a guide and had few fixed observation points, to enable the observer to be more flexible and time-efficient. This protocol produced less quantitative information but this was however not prioritized. In study I, most routine procedures, apart from feeding, were never observed in practice, as most herds were small and the farmers could not both pay attention to the author and tend to the pigs simultaneously. This level of uncertainty was acceptable for the purposes of this study, however in practice, closer practical observations might be necessary in cases where a particular problem continue to occur, despite anamnestically adequate routines.

Examples of interview and observation guides for both the primary and secondary visits are included in the appendix.

3.4 Production figures

Since the farmers themselves had not kept adequate and reliable records prior to the study, data was collected from the visits and from the farmers' records kept during the study, and processed to generate production figures, as these are very important to be able to identify health and productivity issues (Blocks *et al.*, 1994; Basinger, 1985; Goodwin, 1971). Many of the production figures are however better interpreted as an average of all herds, as single events might disproportionally affect the figures in a small herd. As the distinction between different age categories in Uganda is often not exact, a grower was in this study defined as a pig after weaning until slaughter or the first service, and an adult was in this study defined as a pig after the first service.

The ADG was calculated for three age categories; 0-3 months, 3-12 months and 0-12 months, to correspond to the respective growth in piglets, finishers, and to the overall growth in the pigs. Three months were chosen as the cut-off time-point as it is the approximate time when pigs in intensive systems are moved to the finishing unit (INTERpig, 2017). Since pigs often are kept for a longer time-period before slaughter in Uganda, 12 months were chosen as the upper limit for grower/finisher pigs, excluding gilts that had been served. Due to practical reasons, most growers were not weighed but instead measured with a tape, and the live weights were predicted by the formula provided by Mutua *et al.* (2011b). The formula has been shown to explain about 90% of the weight/length variation, and was thus deemed to be a practical alternative to a weighing scale. The spring scales used to weigh the piglets were very simple and provided inaccurate readings in many herds when they were tested with a calibration weight of 1 kg, but the inaccuracy was consistent for each scale and thus possible to adjust for.

Several of the reproductive figures were not possible to calculate, as the farmers could not provide sufficiently detailed information. For example, the farmers could often not accurately detect heat, did not record or was not able to recount the date(s) of reproductive events apart from the farrowings, and/or practiced uncontrolled breeding. Thus, the weaning-to-estrus interval and returns to estrus (regular or irregular) could not accurately be calculated, and the lactation lengths included some uncertainties. Further, since the age of the sows in most cases were retrospectively approximated, age at first service or first farrowing could not be accurately calculated. The farrowing interval only included sows that farrowed twice during study I (31/76 sows from ten herds), and thus, this figure might be artificially low.

The mortality rates included animals that were severely ill, but slaughtered for financial reasons before dying of the disease. This might have affected the mortality rates, however, this can be viewed as a kind of euthanization, and is also included in the mortality rate calculations from pig herds in high income countries. Piglets in Uganda are often sold immediately after weaning, therefore the pigs that were sold within a week after weaning were not included in the calculations of grower mortality rates.

Wealth assessment

The farmers' socioeconomic position was assessed by a simplified protocol modified from the Demographic and Health Survey (DHS) program from Uganda (UBOS, 2018). A relative wealth index was calculated with a maximum score of 13, see Table 1. Commercially run farms, managed by an employed manager, were not included in the assessment (n=4).

Table 1. *Household belongings and characteristics used to calculate a relative wealth index for Ugandan smallholder pig farmers, modified and simplified from the Demographic and Health Survey program from Uganda (UBOS, 2018).*

	Score				
	-1	0	1	2	3
Hygiene					
Access to clean water	>30 min. one way	<30 min. one way	At home		
Toilet	No latrine	Pit latrine	Ventilated improved latrine	Water closet	
Construction					
Floor		Earth	Cement	Tiles	
Roof		Straw	Iron sheets	Tiles	
Walls		Earth/clay	Cement/bricks		
Belongings					
TV		No	Yes		
Transportation		No	Bicycle	Motorcycle	Car
Bed	No	Yes			
Owns land for agriculture		No	Yes		

3.5 Targeted sampling

Targeted sampling such as necropsies and/or collection of tissue, blood, feces or bacterial swabs was performed when clinically indicated (study I). This could *e.g.* be the case if recurring clinical signs were found upon the clinical examinations, indicated through anamnestic information, or if several pigs displayed similar clinical signs. The pigs to be sampled were selected to be representative of the particular clinical problem in the herd, *i.e.* acutely sick, untreated pigs of the typical age and displaying typical signs of the disease. However, this was often not possible, since the herds were only visited by the author for a short time period every second month. Consequently, the samples were sometimes taken from seemingly healthy pigs (*e.g.* blood), or from chronically affected (*e.g.* tissue samples) or treated pigs (*e.g.* feces). Likewise, sometimes suboptimal samples (*e.g.* fecal samples) had to be collected if the owners refused the collection of optimal samples (*e.g.* necropsy). The samples were consequently analyzed for the suspected pathogens. The necropsies focused on finding the cause of the clinical problem, however, skin, lungs, heart, liver, spleen, kidneys, intestines and lymph nodes (tracheobronchial, mesenteric and inguinal), were always examined macroscopically for *e.g.* color, size, consistency, content and/or the presence of visible parasites. Lung, heart, liver, kidney, small and large intestines and mesenteric lymph nodes, along with macroscopically visible lesions, were sampled for histological examination from each pig, however, one piece of tissue from each of three pigs were lost in the embedding process. Tissue samples were collected immediately after euthanization, put in formalin for fixation and transferred to 70% ethanol after 2-4 days to avoid overfixation. Samples were consequently paraffin-embedded in Uganda, transferred to Sweden, and sectioned, stained with hematoxylin and eosin (HE) and examined with light microscopy by a Swedish pathologist. Other stains such as Warthin-Starry stain were prepared if indicated. Tissue sections were overall of good quality.

In herds where the farmers suspected ASF due to acute severe disease in one or several pigs, blood samples (EDTA) were collected, frozen and analyzed by PCR for the presence of ASF virus according to King *et al.* (2003) at the Makerere University. To assess any previous exposure to a potentially low-virulent strain of ASF in the same herds, analyses by serology were also planned, however, it was not performed due to the lack of commercial kits at the laboratory.

Feces were analyzed at the field laboratory in Lira for the presence of endoparasitic eggs and oocysts by a simplified McMaster flotation (Monrad *et al.*, 1999), using both saturated sugar-salt solution and saturated magnesium sulphate. In the literature, saturated magnesium sulphate is recommended to detect eggs of *Metastrongylus* spp. (Taylor *et al.*, 2007). However, the saturated sugar-salt solution is more easily prepared and disposed of in these settings, and thus, the analyses were performed using both solutions to investigate any possible difference. Eggs of *A. suum*, *Metastrongylus* spp., *T. suis*, strongyle-like eggs (*Oesophagostomum* spp., *Hyostrongylus rubidus* and *Globocephalus urosubulatus*), and coccidial oocysts were counted, while eggs of *S. ransomi* were not included due to uncertainties in the identification. Fecal flotation is cheap, simple, and widely used in routine diagnostics. It might however generate false-negative results during the acute stage of infection, when the parasites damage the tissues and induce clinical signs, but before the adult worms or sexual stages of coccidia have started to shed eggs and occysts, respectively. This is especially relevant for *A. suum*, as most of their larvae are expelled before reaching the adult stage and producing eggs (Roepstorff *et al.*, 1997), and thus, fecal examination may underestimate the true prevalence (Vlaminck *et al.*, 2012).

Bacterial swabs were taken from the site of the suspected infection, such as the skin, intestines (or rectum), lymph nodes and the liver, and cultured on blood agar plates at the field laboratory in Lira. Pure-cultures of bacteria were transferred to Sweden and analyzed by MALDI-TOF for species identification, by broth micro-dilution for antibiotic susceptibility, and by PCR for the presence of the virulence factors LT, STa, STb and V2e in *E. coli* at the Swedish National Veterinary Institute, since these analyses were not readily available in Uganda. The laboratory did not perform PCR for staphylococcal toxin genes, and these were thus not included.

Other analyses were, even if they might have been clinically indicated, not performed because of practical reasons. Many relevant analyses were not practically possible to perform, especially not in small quantities, or were not available as routine diagnostics at the facilities in Uganda. For example, piglets with diarrhea may suffer from mixed infections with *e.g. Cystoisospora suis* and rotavirus (Katsuda *et al.*, 2006), but in our study, only analyses for coccidia were performed. Rotavirus have been found in healthy pigs in Uganda (Amimo *et al.*, 2017; Amimo *et al.*, 2015) and it is likely that rotavirus-associated piglet diarrhea occurs in Uganda as well but the most common method for identification, RT-PCR on feces, was not available. In many countries, coronaviruses causing diseases such as transmissible gastroenteritis (TGE) and porcine epidemic diarrhea (PED) are important enteric pathogens, and the endemic form might be confused with other types of diarrhea in suckling piglets and recently weaned pigs (Saif *et al.*, 2019). In seronegative animals however, TGE often induce clinical disease in all ages, with high mortality rates in suckling piglets. To our knowledge, TGE virus has not been reported in Uganda since 2001 (OIE, 2020) and no studies on the virus have been scientifically published. However, two academic theses have reported on the presence of antibodies to TGE in pigs in Gulu, a neighboring district to Lira, finding low (10%; Ikwap, 2015) or no (Muley, 2012) serological response. Thus, analyses targeting TGE and PED were not prioritized. Reproductive pathogens apart from parvovirus, such as *e.g. Brucella suis*, might have contributed to the poor reproductive performance, however, *Brucella suis* has not been reported in Uganda since 2008 (OIE, 2020) and in a more recent study, neither antibodies to, nor DNA of, *Brucella* spp. were found in pigs (Erume *et al.*, 2016). Bacteriological cultivation of *Brucella* spp. was also not an option since the author did not have access to a biosafety level 3 laboratory. In addition, there are numerous viruses and bacteria that might have contributed to the coughing reported by the farmers, but since only mild clinical signs were observed in single pigs, analysis of respiratory pathogens apart from parasites were not prioritized. Additionally, another PhD project have simultaneously been studying respiratory pathogens in the same district[2].

2. P. Oba, in manuscript

3.6 Screenings

By the aid of the VHHM, several disease-related issues were identified that were deemed likely to be important to many of the pig producers in Lira. These included 1) ectoparasites (study I), due to the large amount of skin lesions, the often visibly demonstrated parasites and pruritus, 2) endoparasites (study I), due to the poor growth, suboptimal control measures, and the high numbers found in previous studies, 3) parvovirus (study I), due to the small litters, the birth of mummified fetuses and the lack of vaccination, and 4) antibiotic resistance of *E. coli* and *Staphylococcus* spp. (study II), due to the relatively high use of antibiotics, especially oxytetracycline, the high levels of antibiotic resistance in bacteria isolated from clinical samples, and the general lack of knowledge on AMR (Katakweba *et al.*, 2012). These issues were thus investigated further through screenings in all herds.

3.6.1 Ectoparasites

All pigs in the small herds and all breeding stock in the larger herds were investigated for the presence of visible external parasites (lice, fleas, ticks and jiggers) by a thorough clinical examination at the first visit. If any ectoparasites were found at inspection during the consecutive visits, these were also noted.

Further, the presence of *S. scabiei* was investigated by ear scrapings, since the diagnosis is not possible to make based on clinical signs only (Alonso de Vega *et al.*, 1998; Hollanders & Castryck, 1989). To pre-test the methodology, several pigs in several herds were sampled and analyzed using three simplified methods; direct microscopy, microscopy following incubation, and microscopy following incubation in potassium hydroxide. As no *S. scabiei* were found, the analysis used in the screening also included a flotation with a saturated sugar-salt solution to increase the sensitivity (Alonso de Vega *et al.*, 1998). One to five pigs in each herd were sampled, targeting pigs with signs indicative of mange, such as pruritus, erythema or papules and hyperkeratotic lesions, to increase the likelihood of detecting any positive samples. All analyses were performed at the field laboratory in Lira.

3.6.2 Endoparasites

In each herd, pigs from three different age categories were targeted for the screening; weaned pigs up to 4 months of age, grower pigs 4-12 months old, and sows/gilts in the period from one month before to one week after farrowing. Similar to many other studies (Schubnell *et al.*, 2016; Carstensen *et al.*, 2002), different age categories were selected as many endoparasitic infections are age-related. For example, peri-parturient sows were chosen since they may excrete more eggs during this period (Jacobs, 1966), potentially leading to early infection of the piglets. Up to three samples were pooled per category, and analyzed by a simplified McMaster flotation (Monrad *et al.*, 1999), as described in section “3.5 Targeted sampling”. The screening was performed during two consecutive primary visits to increase the number of herds where all categories could be sampled, however, only two herds were sampled for all three age categories. While growers were sampled in most herds, weaners and sows in the periparturient period were only found and sampled in half of the herds, respectively.

3.6.3 Parvovirus

In total, 43 pigs were bled and the sera were later analyzed for anti-parvoviral antibodies by a commercial enzyme-linked immunosorbent assay (ELISA, Ingezim PPV Compac, Ingenasa, Madrid, Spain) according to the manufacturer’s instructions, at the Central Diagnostic Lab at Makerere University. To increase the likelihood of finding affected herds, preferably, sows with previous signs indicative of parvovirus infection, such as have been giving birth to mummified fetuses or small litters, were sampled. This was however not the case in most herds, where instead sows, gilts or growers, in falling order, were selected for sampling.

Analyses to detect the presence of the virus were not performed since these mainly relies on analysis of fetuses and placentas that were not encountered during the visits, except in a sow that ate her mummified fetuses before they could be collected. Serology is usually not the preferred diagnostic method, since the pathogen is very common and most large intensive herds have vaccination programs. However, only low levels of anti-parvoviral antibodies have previously been detected in Lira (3.4%; Dione *et al.*, 2018) and none of the herds vaccinated their pigs, and thus, serology was considered relevant.

3.6.4 Antibiotic resistance in *Staphylococcus* spp. and *E. coli*

To investigate the occurrence of antibiotic resistance in the herds, two commonly found and fastidious bacteria were targeted. *Staphylococcus* spp. were investigated as Gram-positive bacteria, and MRSA was targeted specifically due to its zoonotic importance. Further, while human carriage of MRSA in Uganda has been associated with pig contact (Bebell *et al.*, 2017), studies on the presence of MRSA in pigs are lacking. *Escherichia coli* were chosen as Gram-negative bacteria, since it is one of the most commonly used bacteria for monitoring AMR, and since it is easily cultured and identified through standard methods. Further, its resistance generally correlates with antibiotic usage (Chantziaras *et al.*, 2013; Dunlop *et al.*, 1998).

Weaners of approximately two months of age were targeted for *Staphylococcus* spp. and MRSA, since they are reportedly more often colonized by MRSA than other age categories of pigs (Moon *et al.*, 2019; Bangerter *et al.*, 2016). In the analysis of *E. coli*, finishers of approximately six months of age were targeted to mimic the age category sampled within the European surveillance program for AMR (EFSA *et al.*, 2019). Pigs close to these ages were not always available at the screening visit, and thus, the median age for pigs sampled for *Staphylococcus* spp. and *E. coli* was 5 months and 7 months, respectively.

Antimicrobial susceptibility testing

As recommended in the European surveillance programs, broth micro-dilution was used for antibiotic susceptibility testing and the minimum inhibitory concentrations (MIC) were compared to epidemiological cut-off values (ECOFF) from EUCAST (2020, retrieved Jan 2020) to define non-wild types (EFSA *et al.*, 2019). Non-wild type isolates are in this text referred to as resistant, which do not necessarily imply clinical resistance. When the ECOFF for an antibiotic was not found in the EUCAST database, only the MIC was reported and the antibiotic substance was not included in assessments of *e.g.* multi-drug resistance. When specific ECOFF were not found for a particular staphylococcal species, the ECOFF for *S. aureus* was used to assess the resistance. An alternative would have been to retrieve cut-off values from other sources, such as *e.g.* the Clinical Laboratory Standards Institute (CLSI), in these cases, however, since the values from EUCAST and CLSI originate from different populations, using both sources might have confounded the results.

The analyses were performed using commercial plates according to the manufacturers' instructions. The strains ATCC 29213 (*S. aureus*) and ATCC 25922 (*E. coli*) were used as controls, and purity and density controls were performed for each sample, including the control strains.

The isolates of presumed *Staphylococcus* spp. were transported to Sweden and further identified by MALDI-TOF MS, and the presumed MRSA also by PCR according to Pichon *et al.* (2012).

3.7 Statistics

In study I, statistics were performed using Welch *t*-tests, or, if paired samples was compared, paired *t*-tests (Excel, Microsoft, Redmond, Washington, USA). In study II, statistics were performed at herd level, using Fisher's exact test (https://epitools.ausvet.com.au/twobytwotable).

4 Results and discussion

A selection of results are presented and discussed in this section. For a full report of the results, see study I and study II.

4.1 General herd characteristics

The average farmer kept less than 20 pigs (median 5) and less than three sows/year (median 1.33). The initial inclusion criteria of keeping the pigs confined or tethered might have resulted in the selection of less low-input pig herds than the Ugandan average. However, ten herds sometimes kept their pigs on free-range and the housing of the pigs also varied within herds both over time and between age categories. Despite the inclusion criteria, one herd did not keep gilts/sows, and an additional two herds did not produce any piglets during the study period.

The quantity of feed and water provided to the pigs was generally too low, resulting in malnutrition and poor growth rates, and probably also lower milk yields, higher susceptibility to diseases and deaths. The basis of the feed in all herds was maize bran, cassava and forage or crop residues, solely or in combinations, and commercial feed formulations were only given to recently weaned pigs in one herd. Other additives, such as *e.g.* fish, salt, or blood meal, were usually not provided. The extensive use of many of these alternative feed sources may result in too low energy and/or protein allowance for the pigs (Muthui *et al.*, 2019), but have, despite poor growth rates, been shown to be more cost-effective in Uganda (Carter *et al.*, 2017a). However, that study was based on *ad lib* feeding of the pigs, and included a balanced variety of feed, not only *e.g.* sweet potato wines but also for instance avocado and jackfruit. To include these feed stuffs, that could otherwise be consumed by humans, in the feed formulation may not always be feasible for the farmers (Carter *et al.*, 2017b).

Biosecurity was generally lacking (Fig. 3). While six farmers confined all their pigs, 16 herds mixed their pigs with others during service, and only two herds never had contact with foreign pigs. The use of quarantine for newly acquired pigs was uncommon. Some farmers claimed to use disinfectant boot baths, but these were either not used in practice or used without prior cleaning of the boots. Age segregation was observed in one herd only, and all in-all out was not practiced. On the other hand, the pig density for the confined pigs was generally low, as compared to *e.g.* Swedish legislation (Statens jordbruksverks föreskrifter och allmänna råd om grishållning inom lantbruket m.m., SJVFS 2019:20, Swedish Board of Agriculture, 2019), and the confinements were often reasonably clean from visible feces. However, the pens were seldom cleaned with water and detergents, and were rarely disinfected. In many cases such procedures were not practically possible, due to *e.g.* earth flooring or poor constructions, but it might also have been due to the lack of knowledge or money (Nantima *et al.*, 2016).

Figure 3. A stray pig and a chicken outside a confined herd. Photo: Jenny Larsson.

Eighteen farmers claimed to perform routine deworming, however, none conducted the treatments according to the initial description, a discrepancy that would not have been detected in cross-sectional studies. Antibiotics were given as a routine or preventive treatment at least once in nine herds (study II). As the routine use of antibiotics in livestock probably neither will increase the productivity in smallholder farms, nor improve the food security or alleviate the protein undernutrition of poor people in the developing countries (Collignon *et al.*, 2005), the practice should be discouraged.

4.2 Production performance

The production performance was generally poor, however varying considerably between the herds. This indicates the large potential for improvement that are present within the current production systems.

Growth

The overall ADG was 101 g/day, corresponding to a live-weight at 6 months of approximately 20 kg (Fig. 4). This is similar to growth rates reported from Kenya and Tanzania (68-150 g/day; Lipendele *et al.*, 2015; Carter *et al.*, 2013; Mutua *et al.*, 2012; Wabacha *et al.*, 2004), but considerably lower than the EU average of >800 g/day in finishing pigs (INTERpig, 2017). The low ADG is likely mainly caused by the poor feeding and the presence of clinical and subclinical diseases, but might also be related to *e.g.* a suboptimal potential of the present breeds.

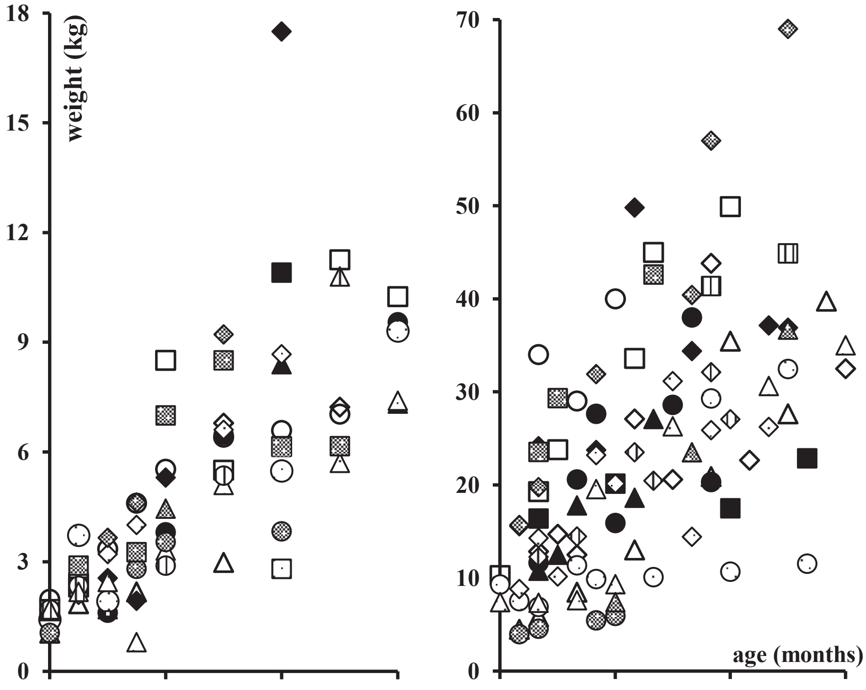

Figure 4. The variation in weights of pigs at different ages in 20 smallholder herds in Lira, Uganda. Each dot represent the average weight per herd and pig age given in weeks up to one month of age, and thereafter in two-week intervals. Weights are not available for all herds at all ages. Dots with the same appearance represent the weights in one herd.

Poor nutrition thus remains as one of the biggest issues for the smallholder pig farms, but it is not only a financial problem. The farmers with the high wealth index (WI; 7-9) had on average numerically lower total ADG than other farmers (Table 2). The reasons for these discrepancies are unknown, but farmers with high WI might not have been equally dependent on the outcome of the pig production, and thus less engaged in the business. Further, the herds with the highest WI never kept their pigs on free-range, whereas herds that routinely allowed their pigs to roam freely had numerically higher ADG.

Some good and poor examples of growth rates and their probable causes can be described. Four small herds with a medium wealth index (WI 3-6) had an ADG of more than 150 g/day in their pigs. The pig health in these herds seemed good apart from subclinical endoparasitic infestations and lice, and the farmers seemingly fed their pigs larger quantities of feed. For example, one herd achieved this through feeding the pigs leftovers from near-by hotels and their at-home business of alcohol production, while another reduced the number of pigs, thereby strongly increasing the growth of the only remaining pig. In contrast, the lowest ADG were found in both a commercial large herd and in small herds. The commercial herd suffered from severe clinical problems with endoparasites, and they prioritized buying expensive premixes while otherwise feeding very small quantities of feed. One of the small herds kept many growers and was not able to buy feed for them, resorting to only small quantities of home-grown raw cassava and forage as pig feed. This resulted in emaciated pigs, and some animals presumably starved to death. In both cases, the farmers were in the end unable to find buyers for the pigs due to their poor condition. Farmers were however unwilling to euthanize any pigs, resulting in a “catch-22”.

Table 2. *Average daily gain (ADG) in pigs in Lira, Uganda, from herds with different wealth indexes, management systems and herd sizes. No statistically significant differences were detected.*

	ADG 0-12 months, g/day
Wealth index	
Low, 0-2 (n=4)	105
Medium, 3-6 (n=9)	118
High, 7-9 (n=3)	64
Keeping pigs routinely on free-range	
Yes (n=4)	120
No (n=16)	100
Herd size	
Large (n=5)	87
Small (n=15)	107

Reproduction

Reproductive performance was generally poor, with few litters and few piglets per litter (Table 3). Factors such as heat stress, low parity numbers, breed, the presence of various pathogens, and poor nutrition in sows and boars might all have contributed to these results (Hagan & Etim, 2019; Langendijk *et al.*, 2017; Bloemhof *et al.*, 2013; Mengeling *et al.*, 2000; Wettemann *et al.*, 1976), however, poor reproductive management likely contributed to a large extent. The standing heat was only mentioned by one farmer. Instead, farmers detected heat mainly by the observation of reddening and swelling of the vulva, signs that are generally observed two-three days before the standing estrus and ovulation (Sterning *et al.*, 1994). Further, external estrous signs are more prominent in gilts, but the intensity and duration of these signs are reduced in lean gilts (Eliasson, 1991). Nevertheless, half of the farmers immediately brought the sow to a boar (or vice versa) when external signs were detected, and equally many also left the sow and the boar together for less than a day. Thus, some farmers might have served their females at inappropriate time-points, leading to *e.g.* return to estrus or small litters (Steverink *et al.*, 1997; Soede *et al.*, 1995). For example, one large herd faced problems with repeated estrus. Their sows were brought to the boar shortly after the first detection of external signs of estrus, and they remained together for less than a day. The manager reported that the sows often still "wanted to go to the boar" after returning to the pen, but that they never brought them back. However, as previously stated, detailed information of reproductive events was often missing, and the reproductive management needs to be studied in further detail.

Table 3. *Figures on the reproductive performance in 20 smallholder pig herds in Lira, Uganda, based on written or oral statements, during the period July 2018 to June 2019.*

Parameter	Average	Range
Lactation length (days)	43	17-59
Farrowing interval (days)	188	141-236
Abortions (%)	2.4	0.0-50.0
Stillborn piglets (%)	6.6	0-38.5
Litters/sow/year	1.6	0-2.4
Total no. of piglets born/litter	8.7	5.0-12.0
Piglets born alive/litter	8.2	4.0-12.0
Piglets born alive/sow/year	13.2	6.2-20.1
Piglets weaned/litter	6.9	4.0-9.6
Piglets weaned/sow/year	11.1	5.1-18.0

Poor reproductive performance has been described in other sub-Saharan countries (Abah *et al.*, 2019; Mutua *et al.*, 2011c; Wabacha *et al.*, 2004), but the problem seems to have been overlooked in Uganda. Similar to the present study, when a value-chain assessment was performed in Uganda, pig producers did not mention breeding-related constraints such as *e.g.* few litters per year (Ouma *et al.*, 2015). Instead, most farmers discussed poor growth or high mortality rates as constraints to the productivity. This might be due to a general lack of knowledge on reproduction, or a belief that reproductive performance cannot be improved. However, it might also not be desired by all farmers to increase the reproductive performance, *e.g.* if they will not be able to adequately feed the sows.

Mortality rates

Mortality rates (Table 4) were on average higher than the EU average (INTERpig, 2017). Suckling piglets mainly succumbed due to seemingly non-infectious causes such as crushing (45%; 45/101), "weakness" (13%) and savaging (11%), which is in line with previous research from both high income countries (Kielland *et al.*, 2018; Koketsu *et al.*, 2006), Uganda (Biryomumaisho & Ogalo, 2007), and other sub-Saharan countries (Abonyi *et al.*, 2012; Wabacha *et al.*, 2004). In contrast, farmers more often reported signs suggestive of infectious disease as the cause of death in growers, mainly diarrhea (at least 46%; 31/67). Respiratory signs were only associated with deaths in one herd. The sow mortality were reported to be due to systemic disease (inappetence and weakness with or without other signs; n=3), heat stress and lack of water (n=1), trauma (n=1) and dystocia (n=1).

Table 4. *Mortality rates (%) in different age categories of pigs from 20 smallholder herds in Lira, Uganda. n = the total number of pigs present in each category*

	Average	Median	Range
Suckling piglets (n=671)	15.1	11.1	0-24.2
Growers (n=694)	9.7	6.9	0-57.1
Sows (n=76)	7.9	0.0	0-100

4.3 Health and disease

In all herds, different abnormalities were found at the clinical examinations, by the targeted sampling and/or in the screenings, however the problems varied considerably between the herds. An overview of the different clinical signs and their causes can be seen in Table 5. As described below, endo- and ectoparasites were very common, causing problems ranging from possible subclinical effects to overt, and sometimes severe, clinical disease. Behavioral disorders such as tail biting were not noted in any of the herds, and shoulder ulcers were only seen in one sow in the largest herd.

4.3.1 Health surveillance

Apart from skin lesions and pruritus, diarrhea was the most common clinical sign, affecting both piglets, recently weaned pigs and growers. Diarrhea seemingly also caused the largest impact on the productivity, both regarding mortality rates and weight losses, emaciation and affected growth. Similarly, gastrointestinal disturbances affect pig herds all over the world, although the pathogens involved might differ. For example, endoparasites are an uncommon cause of clinical disease in intensively managed pig herds (Thomson & Friendship, 2019; Kipper *et al.*, 2011).

Diarrhea in suckling piglets was generally noted as mild steatorrhea affecting a few-week-old piglets, but one herd reported more profuse watery neonatal diarrhea at one occasion. Only six per cent of the total piglet mortality was caused by diarrhea (6/101), however, farmers commonly reported emaciation of the affected litters. Two piglets, suffering from steatorrhea, from two different herds were subjected to necropsy and diagnosed with coccidiosis (presumably *Cystoisospora suis*), and helminthosis (presumably *S. ransomi*), respectively. Coccidiosis caused by *Cystoisospora suis* is a common cause of piglet diarrhea in intensive pig production in other countries (Katsuda *et al.*, 2006; Wieler *et al.*, 2001), and its presence was expected. However, neither the farmers or the extension workers in study I, nor in other studies (Roesel *et al.*, 2017; Dione *et al.*, 2014a; Dione *et al.*, 2014b), have mentioned the use of coccidiostats, possibly indicating a lack of knowledge on the disease. *Strongyloides ransomi* may be transmitted from the sow to the offspring in a number of ways, *e.g.* through colostrum (Stewart *et al.*, 1976; Moncol, 1975), resulting in early infection and diarrhea of the suckling piglets (Thomson & Friendship, 2019). The parasite is seemingly rare in high-income countries (Schubnell *et al.*, 2016; Roepstorff *et al.*, 1998; Eysker *et al.*, 1994), possibly due to higher hygiene levels and the frequent use of ivermectin (Thamsborg *et al.*, 2017) but have been found, sometimes in high numbers, in Uganda and neighboring countries (Roesel *et al.*, 2017; Kabululu *et al.*, 2015; Kagira *et al.*, 2012). It may thus be considered as a cause of piglet diarrhea in Uganda and similar settings.

Severe diarrhea in pigs shortly after weaning resulted in increased mortality rates and affected growth in both small and large herds. In the two herds where diarrhea was observed, enterotoxigenic *E. coli* were found both in the rectum of

Table 5. An overview of different clinical signs, the suspected causes, the occurrence (O) and the severity (S) in 20 smallholder pig herds in Lira, Uganda, during July 2018 to June 2019.

Clinical sign	Suspected causes[1]	O[2]	S[3]	Comment
Skin				
Pruritus	***Ectoparasites	++	(+)	Lice, fleas and jiggers found. *S. scabiei* not found but suspected
Deep wounds	**Tethering ropes	++	(+)	Mainly around the neck or the extremities
Exudative epidermitis	****S. sciuri* ** *S. hyicus*	(+)	+	Affected retarded 4-5-month-old pigs in one herd
Multiple raised, round, sometimes umbilicated, papules, ulcers and crusts	**e.g.* swine pox, vesicular diseases, ectoparasites, bacterial infections	(+)	-	Epidemic in growers in two herds, no further investigations were performed
Respiratory tract				
Cough	****Metastrongylus* spp., *A. suum* *Respiratory viruses or bacteria	++	+	Mild interstitial, eosinophilic pneumonia was commonly found at necropsy in pigs without affected general demeanor. However, one herd reported deaths in conjunction with cough. No laboratory analyses for bacteria or viruses were performed
Increased respiratory rates, panting	**Heat stress, stress or pain	++	(+)	
Gastrointestinal tract				
Dry feces	**Lack of water	++	(+)	Water was usually not offered *ad lib*
Diarrhea				
- Piglets	****Cystoisospora suis*, *S. ransomi* ** Enterotoxigenic *E. coli* (ETEC)	++	+	Generally mild, creamy diarrhea affecting a few-week-old piglets. Neonatal profuse watery diarrhea in one litter in one herd that also suffered from post-weaning diarrhea caused by ETEC
- Growers <1mth post-weaning	***Post-weaning diarrhea (ETEC)	++	++	Investigated strains generally resistant to tetracycline, amoxicillin and streptomycin.
- Growers >1 mth post-weaning	****Trichuris suis*, other endoparasites	++	++	*Lawsonia intracellaris* and *Salmonella* spp. were not demonstrated
Reproduction				
Small litters	***e.g.* reproductive management, nutrition, heat stress, parvovirus	++	++	Seven herds had on average <6 piglets born alive/litter

Clinical sign	Suspected causes[1]	O[2]	S[3]	Comment
Mummified fetuses	***Parvovirus	+	++	9% and 16% of the total number of piglets born in two herds, respectively
Agalactia	*High body condition score and underlying chronic illness	(+)	++	Reported in one sow. The piglets possibly never received colostrum and all died of diarrhea at three months of age
Locomotor system				
Arthritis				
- Suckling piglets	**Rough floors, no bedding and suboptimal cleaning	+	+	Two cases of chronic arthritis and retardation in the largest herd, having concrete floors
- Growers/adults	***Erysipelothrix* infection	+	+	One herd reported arthritis, inappetence, weakness and red skin lesions that generally were responsive to antibiotic treatment
Sudden "paralysis" of limbs	**e.g.* infectious agents, osteochondrosis, lack of selenium/vitamin E, trauma	+	(+)	Never observed, only described. Reportedly responsive to antibiotics
Systemic disorders				
Fever/shivering, inappetence, weakness, discoloration of skin, death	**e.g.* African swine fever, *Erysipelothrix* infection, porcine reproductive and respiratory syndrome	+	+	Three herds reported single episodes. Affected pigs had been on free-range. Two herds had several pigs that remained healthy and that were PCR-negative for ASF.
Sudden death	**Heat stress/lack of water	(+)	+	One of the two herds had water nipples repeatedly out of order

[1] Probable or verified causes; *** infectious agent or antibodies demonstrated; ** anamnestically or clinically suspected causes; * possible differential diagnoses

[2] Occurrence of clinical signs is graded as; (+) single occasions in 1-2 herds; + multiple occasions in 1-2 herds or single occasions in 3-10 herds; ++ multiple occasions in 3-10 herds or single occasions in >10 herds. An occasion is defined as clinical signs in one or many pigs, observed during the visits or described by the farmers

[3] Severity is graded for the affected herds as; – likely not affecting production, (+) possible productivity effects; + minor productivity effects; ++ major productivity effects. Productivity effects is defined as negative effects on weight/body condition, weight gain and/or the number of pigs related to the presence of clinical signs. Minor effects is defined as negative productivity effects in an estimate of <10% of the pigs in the affected herds, and major effects as effects in ≥ 10% of the pigs in the affected herds.

sick and in the intestines of necropsied pigs. Post-weaning diarrhea (PWD) associated with ETEC is a multifactorial, important and very common disease in pig production globally (Rhouma *et al.*, 2017; Fairbrother *et al.*, 2005). In intensive pig production, PWD has been associated with many factors such as piglet condition at weaning, different housing conditions (*e.g.* poor hygiene, low temperatures, draught, high stocking density and high number of pigs per pen), and suboptimal feeding regimens (*e.g.* low feed intake after weaning, inadequate feeding space and composition of feed; Rhouma *et al.*, 2017; Lofstedt *et al.*, 2002; Madec *et al.*, 1998). The herds in study I in which diarrhea was observed were comparatively large and had a more "intensive" production as compared to the other herds. A number of areas for potential improvement were identified, such as *e.g.* the lack of a creep area and creep feed, varying, sometimes poor, condition of the piglets at weaning, restricted quantities of feed given in small feeding troughs (≥8.4 cm per pig), and no regular cleaning of the pens with water, detergent or disinfectants. Further, the ETEC isolated from both herds exhibited resistance to tetracycline, the antibiotic substance that were mainly used in the herds to treat the diarrhea. In the small herd reporting severe post-weaning diarrhea, piglets were in poor condition at weaning, the quantities of feed was limited and the pen hygiene was very poor.

Diarrhea in older growers was observed and/or reported in nine herds, causing major negative productivity effects by increased mortality rates and impaired growth/emaciation in two of the herds. At necropsy, endoparasite-related enteritis, colitis and typhlocolitis were found in pigs from two herds. For example, *T. suis*, possibly potentiated by *Eimeria* spp., caused major problems in a herd with poor housing, cleaning and feeding. In intensive pig production, diarrhea in growers is often caused by bacterial pathogens such as *Salmonella* spp., *Brachyspira* spp., and *Lawsonia intracellularis* (Thomson & Friendship, 2019), all of which have been found in Kenyan pigs (Friendship & Bilkei, 2007). *Salmonella* spp. have been found in pig herds in neighboring districts in association to diarrhea in the pigs (Ikwap *et al.*, 2014a), and salmonellosis was suspected in one herd in study I. Therefore, a swab for cultivation was collected from a mesentery lymph node at necropsy of a diarrheic grower. *Salmonella* spp. were not demonstrated, however, for practical reasons, no selective culturing was performed and the involvement of *Salmonella* spp. cannot be excluded. No typical macroscopic signs or histological evidence of *Brachyspira* spp. were found and no further analyses were performed. Thickened ileal mucosa was seen at necropsy of one grower, but *Lawsonia intracellularis* were not seen in Warthin-Starry silver stains of histological specimens. Porcine circovirus type 2 might also be involved in cases of diarrhea and ill-thrift (Kim *et al.*, 2004), and this has previously also been described in Uganda (Wilfred *et al.*, 2018).

However, since no macroscopic lesions such as lymphadenopathy or microscopic lesions such as lymphoid depletion were seen in the necropsied pigs, further analysis for PCV-2 were not performed.

Suspected cases of African swine fever

Three herds reported cases of suspected ASF, with pigs displaying *e.g.* shivering, inappetence, weakness, discoloration of the skin, and deaths of a few animals in the herds. No cases of ASF were laboratory confirmed during study I, however, the cases occurred in-between two visits when no sampling was possible to perform, and samples were thus taken at the next primary visit in these herds, from healthy pigs that never had shown any of the described clinical signs. The samples were further not analyzed for any differential diagnoses, such as classical swine fever, PRRS or swine erysipelas (Sánchez-Vizcaíno *et al.*, 2015), and no definitive diagnosis of the cases could be made. Classical swine fever and PRRS were deemed unlikely since they have not been reported from Uganda (OIE, 2020), nor been detected in previous studies on suspected cases of ASF (Muhangi *et al.*, 2015). However, preliminary results from a recent study found PRRS virus by PCR in Lira district[3], and thus, PRRS might need to be considered in the future. Serological response to *E. rhusiopathiae* is common in Ugandan pigs (Musewa *et al.*, 2018), and the bacteria have been described to cause clinical disease and mortality in neighboring Kenya (Friendship & Bilkei, 2007; Wabacha *et al.*, 1998). In one of the herds with suspected ASF, one of the two remaining pigs in the otherwise diseased litter developed arthritis, a common sign of chronic swine erysipelas. Other septicemias, such as *e.g.* salmonellosis or acute actinobacillosis, might also present with signs similar to ASF in the individual pig, and without undertaking further diagnostic measures, distinction cannot be made. It is thus possible, as other authors have hypothesized (Nantima *et al.*, 2016; Dione *et al.*, 2014b), that farmers might attribute any severe pig disease, presenting with fever and/or death, to ASF.

4.3.2 Screenings

Ecto- and endoparasites

Similar to the examination of sick pigs, endo- and ectoparasites were commonly found in the screenings performed in study I. Ectoparasites, mainly lice, were found in 13 herds. The presence of *S. scabiei* was anticipated since the mite has

3. Personal communication, DVM Peter Oba, International Livestock Research Institute/Makerere University, 2020

been identified as a common cause of pruritus in Kenya (Wabacha *et al.*, 2004), however, no mites were found in any of the 40 samples in the screening, nor in any samples collected before the screening. It could however not be concluded that *S. scabiei* is absent, only that it was not found, as the mite can be difficult to detect. However, lice were frequently found and may very well be the cause of the commonly noted pruritus.

Endoparasitic eggs or oocysts were found in 19 herds, and in 33% (12/36) of the samples, nematode egg count exceeded 500 EPG. It was also concluded that the saturated sugar-salt solution was superior to the saturated magnesium sulphate in detecting eggs and oocysts of strongyles, *T. suis* and coccidia ($P < 0.05$), while no statistically significant difference between the results from the two methods was detected for *A. suum* and *Metastrongylus* spp. Saturated sugar-salt might thus be recommended as the standard flotation solution in these settings.

The high presence of parasites in study I, similar to the findings in other studies (Roesel *et al.*, 2017; Braae *et al.*, 2013; Nissen *et al.*, 2011; Wabacha *et al.*, 2004), together with the clinical signs that the parasites were observed to inflict, indicates that the farmers' anti-parasitic routines were insufficient. Some farmers claimed to implement an anti-parasitic medical treatment routine, but this was rarely followed, and the drug and dosage used were suspected or confirmed to be suboptimal. For example, the manager of a herd with severe clinical problems of emaciation, diarrhea, and retarded growth in the pigs, suspected "worms" as the cause of the signs. Therefore, he treated the pigs weekly perorally with levamisole given at a dosage of 1-2 mg/kg bodyweight. The dose was far too low as compared to the recommended dosage of 8 mg/kg bodyweight (Karriker *et al.*, 2019). Further, during study I, severe infection with *T. suis* was established as a cause of the herd's problems, but at the recommended dosage of 8 mg/kg, levamisole have a reduced efficacy to *T. suis* (Marti *et al.*, 1978). Lastly, the weekly treatment strategy might have been "over-enthusiastic", since the prepatent period of *T. suis* is 6-8 weeks. However, proper treatment regimens are important, as a history of medical treatment have been associated with lower levels of both endo- and ectoparasitic infestation in smallholder systems (Nwafor *et al.*, 2019; Kabululu *et al.*, 2015; Braae *et al.*, 2013; Kagira *et al.*, 2012). Some ectoparasites, such as *S. scabiei*, might even be eradicated by the use of strategic medical treatments (Jacobson *et al.*, 1999).

Nevertheless, in the control of endoparasitic infections, management factors to decrease parasite survival and transmission also need to be included. In sub-Saharan Africa, endoparasitic infestations have been associated with the keeping of pigs on free-range during the day-time (Nwafor *et al.*, 2019), poor hygiene, poor body condition, and the lack of protein/mineral supplements (Kabululu *et* *al.*, 2015). In contrast, lower levels of infestations have been found in herds that routinely remove feces, regularly use disinfectants (Roesel *et al.*, 2017), keep the pigs on raised, wooden, slatted floors (Nissen *et al.*, 2011), and provide housing, at least during the night (Kagira *et al.*, 2012). Simply put, control strategies should aim at keeping well-fed pigs in clean pens. In the example with *T. suis* described above, the pig house provided optimal conditions for the survival and transmission of parasites. The walls were high and the floors were rough and broken, making them impossible to clean properly. Thus, the pens were always moist and dark with a moderate temperature. Also, the pigs were in poor condition and mainly fed only on small amounts of maize bran.

Parvovirus

Anti-parvoviral antibodies were detected in 35% (7/20) of the herds and 42% (18/43) of the individuals in study I, and none of the herds vaccinated their sows. The high number of mummified fetuses in two of the herds, in the absence of clinical signs in other pigs, were thus presumed to be caused by PPV. Small litters is another feature of PPV infection (Mengeling *et al.*, 2000), a common finding in the studied herds and possibly partly associated to PPV.

Porcine parvovirus is considered to be one of the most important reproductive pathogens in pigs globally (Truyen & Streck, 2019), but the disease has not been discussed as an important pig pathogen in Uganda, and reports of clinical disease in other African countries are scarce (Rivera *et al.*, 1995). Differential diagnoses to parvovirus include *e.g.* pseudorabies, brucellosis, leptospirosis and PRRS (Truyen & Streck, 2019), but these often induce additional signs apart from mummified fetuses and small litters, such as abortion, stillbirths, and neurological and respiratory signs. However, since no analyses for these, or other possible differential diagnoses, were performed, a relationship to other pathogens cannot be ruled out.

Antibiotic resistance of Staphylococcus *spp. and* E. coli

In Uganda, antibiotics are readily available over-the-counter despite the presence of legal regulations (Mukonzo *et al.*, 2013), and smallholder farmers often lack knowledge on AMR (Katakweba *et al.*, 2012). In study II, resistance to frequently used antibiotics, such as tetracycline, penicillins, and sulfonamides with or without trimethoprim, were commonly detected in both *Staphylococcus* spp. and *E. coli* (Table 6). This pattern of resistance has also been described for *E. coli* in Tanzania (Katakweba *et al.*, 2018). Nevertheless, the levels of antibiotic resistance demonstrated in *E. coli* were generally lower than in reports on isolates from pigs in both Africa and Asia (Okubo *et al.*, 2019; Van Boeckel *et al.*, 2019; Katakweba *et al.*, 2018; Strom *et al.*, 2018), and differed from previously published figures in Uganda (Okubo *et al.*, 2019; Okello *et al.*, 2015). It is however hard to compare the figures obtained from different studies of antibiotic susceptibility, since the methods used in the analyses often differ (Lozano *et al.*, 2016; Schwarz *et al.*, 2010). For example, Okubo *et al.* (2019) used cut-off values from a source different from the one used in study II, and Okello *et al.* (2015) used another test method for susceptibility, and analyzed isolates from sick pigs.

While Okubo *et al.* (2019) concluded that treatment with penicillin or tetracycline was associated with resistance to these antibiotics in *E. coli* in Uganda, treatment regimens found in the present study could not be associated to neither overall resistance, nor to specific antibiotic substances or MDR in study II. This might be due to the smaller sample size in study II, as compared to the sample size used in the study by Okubo *et al.* (2019).

The screening also revealed that isolates of *S. sciuri* and *E. coli* from healthy pigs (study II) exhibited similar antibiotic resistance patterns as pathogenic isolates from sick pigs (study I) in the same herds. Antibiotic resistance might thus be an important practical issue in these herds, and might affect the treatment outcome of diseases such as post-weaning diarrhea and exudative epidermitis.

Methicillin-resistant *S. aureus* was found in one pig in one herd, indicating a low occurence, which is in line with previous findings from the continent (Otalu *et al.*, 2018; Van Lochem *et al.*, 2018). As pigs and humans live in close contact in these smallholder farms, MRSA and other antibiotic-resistant strains of bacteria might originate from and colonize any of the species.

Table 6. *The most common types of antibiotic resistance found in isolates of* Staphylococcus *spp. and* Escherichia *(*E.*)* coli *obtained from healthy pigs in 20 smallholder farms in Lira, Uganda*

Bacteria	Antibiotic			
Staphylococcus spp.	PEN (53%)	FA (42%)	TET (37%)	SXT (32%)
E. coli	SMX (88%)	TET (54%)	TMP (17%)	AMP (12%)

PEN = Penicillin, FA = Fusidic acid, TET = Tetracycline, TMP = Trimethoprim, SMX = Sulfamethoxazole, SXT = Trimethoprim-sulfamethoxazole, AMP = Ampicillin

5 Recommendations to improve the herd health in smallholder pig farms

Efforts to improve the herd health must take the specific situation in each herd into consideration. Recommendations must also consider the local context, as it is not necessarily possible to extrapolate advice given in intensive pig production in high-income countries, to smallholders in Uganda. The livestock production and smallholder farmers' motivations differ from intensively managed farms in high-income countries, and the pigs are mainly kept as "banks" for specific needs, not as a source of regular income. Thus, all farmers might not prioritize increased productivity, which must be kept in mind while considering possible interventions. Nevertheless, some general recommendations can be made.

The first priority for all pig herds should be water and feed of good quality and quantity. In too small quantities and in too poor quality, it affects the productivity by *e.g.* affecting growth, reproduction and health (Costermans *et al.*, 2020; Langendijk *et al.*, 2017; Lykke *et al.*, 2013; Pedersen *et al.*, 2002; Zak *et al.*, 1997). This thesis provides examples on how too high number of pigs compared to the level of feed available resulted in very low ADG, and that a reduction in the number of pigs resulted in a comparatively high ADG. Ample amounts of water are also very important in the Ugandan climate to reduce the negative effects of heat stress. However, in a country where more than a fourth of the population live in poverty and about one-third have unacceptably poor food consumption and food diversity (UBOS, 2017), it is ethically problematic to advice farmers to give the pigs diverse feed of good quality that they instead could have been given to their children. Thus, the farmers should be encouraged not to keep more pigs than they can properly feed, water and otherwise manage. This kind of advice might however be difficult for farmers in this cultural context to accept, as it might be seen as a failure to reduce the number of pigs[4]. It might

4. Personal communication, DVM Podpodo Cecil, District Veterinary Office, Lira, 2020

nonetheless be the most important recommendation to give, not only for productivity and economic reasons, but also for the sake of animal welfare.

In the recommendations related to animal health, strategic parasite control should be in focus, as both ecto- and endoparasites were very common, causing both subclinical and overt clinical disease. Ectoparasites should be possible to control by strategic medical treatments in small herds keeping pigs tethered or confined, or even be eradicated in herds keeping their pigs strictly confined. With respect to endoparasites, strategic deworming combined with measures to reduce the load of infectious eggs, larvae and oocysts in the pigs' environment, and their transmission to the pigs, are warranted. Such control measures might *e.g.* include proper feeding, regular removal of feces from pens or tethering areas, thorough cleaning and disinfecting of pens where possible, rotating areas for tethering/pasture and age-segregation of pigs.

The reproductive performance may be affected by many factors, however, accurate heat detection and subsequent service management are essential to increase productivity and to control the production, as the prize of pigs sold for slaughter fluctuate during the year (Atherstone *et al.*, 2019; Ouma *et al.*, 2015). Management might also be easier for farmers to optimize than *e.g.* disease status and heat stress, but requires knowledge to adapt the routines to the various conditions present on each farm.

The poor biosecurity affects the health in many herds. One of the most important aspects to reduce transmission of many diseases, including ASF, is to avoid direct contact between pigs from various farms. Free-ranging pigs remain a problem, but many tethered and confined herds also have contact with other pigs, especially in the farms that use village boars to serve their sows. To avoid contact with a boar of unknown disease status, artificial insemination (AI) have been implemented at a small scale in some parts of Uganda. However, AI relies on accurate heat detection and the possibility to control the temperature under which the semen is kept, and these conditions are often lacking. Biosecurity measures to reduce indirect disease transmission may include a change of boots before entering the pig house, which might be more effective than boot baths in this context, as previously suggested by others (Chenais *et al.*, 2017c).

No vaccination to any pig disease is to the author's knowledge currently used in Uganda, although this may change in the nearby future. Before introducing a vaccination program for smallholder herds, a cost-benefit analysis must however be made. In severely affected herds, or in large-scale, intensive pig production, vaccination programs for *e.g.* ETEC, *E. rhusiopathiae* and PPV might be considered. Although not presently an option, the development and distribution of an ASF vaccine would further be most welcome, as this very serious disease is endemic in Uganda.

Bacteria that had developed resistance to commonly used antibiotics were found in both healthy and diseased animals in the herds included in these studies. While antibiotic susceptibility testing might not be readily available to local animal health workers, they should be aware of the presence of antibiotic-resistant bacterial strains and thoroughly monitor the clinical effect of all treatments performed, as treatment regimens might have to be re-assessed. For example, OTC were found to be ineffective in cases of *E. coli*-associated PWD. While preventive measures, such as *e.g.* thorough cleaning of the pens, age segregation, provision of creep feed, adequate feeding space, and easily digestible feed should be prioritized in herds with recurring problems, treatment of sick pigs is also necessary. Currently, substances combining trimethoprim and sulfonamides seems to be a better choice than OTC for treating PWD in Lira, however, this might change and needs to be reviewed regularly.

In these settings, the submission of diagnostic samples to a laboratory might not always be possible, and the laboratories might not have the ability to perform the requested analyses. Good skills of animal health workers to enable a field diagnosis by clinical examinations and simple farm necropsies are thus very important (Uggla, 2020). However, due to the small size of the herds, it might not be feasible to euthanize and necropsy sick pigs, but rather rely on the examination of already dead pigs. In some cases inspections at slaughter would be an option, *e.g.* for surveillance of parasites or cases where acutely sick animals are slaughtered. Fecal analysis for the detection and quantification of parasite eggs is easy, and can be done at field laboratories with a minimum of advanced equipment, however, a light microscope is needed. Saturated sugar-salt solution proved more or as useful as compared to saturated magnesium sulphate in these settings, and has the benefit of being cheap and easily produced on-site.

Many constraints, including the poor reproductive performance, are partly related to lack of knowledge. Farmers need to have at least basic knowledge in pig management to succeed in their pig production. However, veterinarians and paraveterinarians often also lack knowledge in pig medicine and management, and farmers often describes poor veterinary and advisory services as being constraints to the production (Dione *et al.*, 2014b; Muhanguzi *et al.*, 2012). At Makerere University, the only institution providing a full veterinary education in Uganda, porcine medicine is included in the curriculum, but academic staff specialized in porcine medicine is lacking (Uggla, 2020). Further, practical training of veterinary students is very scarce due to the very few large pig farms available for the students' extended training, and pig medicine have been an unattractive area for specialization[5]. The capacity of paraveterinarians and

5. Personal communication, DVM PhD Kokas Ikwap, lecturer at Makerere University, 2020

veterinarians needs to be increased to be able to offer more farmers high quality services.

6 Future use of VHHM

While studies on single diseases have provided and will continue to provide valuable information, animal health is often affected by multiple factors. Thus, a more holistic approach is warranted. Veterinary herd health management is already widely used in clinical practice in high-income countries, but has less so been applied in research, and literature on this approach is scarce.

Study I showed how VHHM were able to identify both previously described and previously unidentified constraints to the pig production in Uganda. Further, the approach provided information on the clinical relevance of the identified issues. Thus, the method may be used to investigate animal health constraints in low-income countries, and further help to prioritize animal health problems for both future research, policy-making and interventions. The studies presented in this thesis will also be followed up by an ongoing PhD-project, studying how to improve the identified issues, by the continuous use of an extended VHHM, compared to the one used in this study.

The advantage of the VHHM is the holistic, adaptive and participatory process. It may capture animal health issues ranging from infectious disease to management-related problems, including problems that might not have been captured by traditional approaches (Ramirez & Karriker, 2019; Goodwin, 1971). The method also generates information relevant and adapted to the specific context.

While VHHM generates a large amount of information, thorough knowledge on pig production and diseases is needed to be able to interpret the findings. However, to minimize bias due to the previous experience, continuous collaboration with other veterinarians and/or other animal specialists is essential, and laboratory investigations should be included. Further, the iterative process is time-consuming, thus possibly expensive, and this must be accounted for in the future use.

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Popular science summary

Uganda is a low-income country where the majority of the people relies on farming for their living, and pig keeping is becoming increasingly popular. A household generally only have a few pigs, which they feed on locally available feed and keep either in a pen, tethered to a tree or pole, or left to roam freely in the surroundings. The pigs are mainly kept as savings, to sell when a need arises, such as paying school fees or medical bills.

Earlier research have found that poor health and diseases are common problems to the Ugandan pig production. Poor health is often not only due to *e.g.* one bacteria, but rather arises as a result of a combination of many different factors, such as feeding and management, and/or a combination of different diseases. However, previous research have mainly focused on single diseases. The aim of this thesis was therefore to study the overall health in Ugandan smallholder pig farms, to identify which diseases and related problems that are common, and the extent to which they affect the pig production.

Twenty farms were randomly selected from a list of known pig farmers in the study area. In study I, a holistic approach, namely veterinary herd health management, was used. This is a commonly used method in veterinary clinical practice and in this study, it included monthly farm visits during one year using interviews, observations, clinical examinations, and sampling for laboratory analyses to identify health and productivity constraints. By the use of this method, some disease-related issues, such as parasites, parvovirus and the development of antibiotic resistance, were suspected to be of importance in several herds, and were studied in further detail in all herds (study I+II).

The results showed that the general health and productivity of the pigs were poor, but that the situation varied among the herds. A sow produced on average 11 weaned piglets per year, the average daily weight gain of pigs in the age interval 0-12 months was 101 g/day, and mortality rates in suckling piglets, growing pigs, and adult sows were 15.1%, 9.7% and 7.9%, respectively.

Most farmers did not feed their pigs adequately, using too small amounts of feed and using feedstuffs that were not suitable for pigs as a single feed source. This resulted in very low growth rates in the pigs, as compared to pigs in large farms in Europe. The sows gave birth to few litters per year, and with few piglets per litter. There may be many reasons for this poor reproduction, such as heat stress, different bacterial, viral or parasitic infections, and poor nutrition, but it is also possibly linked to the management of the pigs, as most farmers were unaware of how to reliably detect heat and when to serve the sows.

Many diseases were found and the most common clinical sign noted was itching, caused by lice and possibly also by mange. Internal parasites such as worms were very common, and the levels of parasite eggs detected in the feces were high. The internal parasites were also related to diarrhea in suckling piglets and growing pigs, resulting in weight loss and even death of some pigs. Severe diarrhea after the weaning of the piglets was observed in the two largest herds, and disease-associated *E. coli* bacteria were demonstrated. Also, resistance to commonly used antibiotics such as tetracycline was found in *E. coli* and in staphylococci bacteria from both healthy and sick animals. Pigs in many herds had antibodies to parvovirus, a virus causing stillborn piglets and small litters. The presence of such signs was also described in many of the herds. A few herds described serious disease and deaths caused by what they believed was African swine fever. This is a common pig disease in Uganda caused by a virus, but the virus itself was not found in the present study.

In conclusion, pig herds in Uganda face a number of health-related problems and all parts of this complex situation needs to be considered in the efforts to improve health and productivity.

Populärvetenskaplig sammanfattning

Uganda är ett låginkomstland där majoriteten av befolkningen är beroende av jordbruk, och där grishållning ökar i popularitet. Ett hushåll har oftast bara ett fåtal grisar, vilka de utfodrar med lokalt tillgängligt foder och håller i en box, fastbunden vid ett träd eller stolpe, eller låter gå helt fria i omgivningarna. Grisarna används framför allt som ett sorts sparkonto, som kan säljas vid behov som t.ex. när skolavgifter eller sjukvårdsräkningar ska betalas.

Tidigare forskning har identifierat dålig hälsa och sjukdom som vanliga problem i ugandisk grisproduktion. Dålig hälsa beror oftast inte bara på t.ex. en bakterie, utan är snarare ett resultat av många olika samverkande faktorer, som utfodring och skötsel, och/eller en kombination av olika sjukdomar. Trots detta så har tidigare forskning framför allt fokuserat på enskilda sjukdomar. Syftet med den här avhandlingen var därför att studera det generella hälsoläget i ugandiska grisbesättningar, för att se vilka sjukdomar och relaterade problem som är vanliga, och om dessa påverkar produktionen.

Tjugo gårdar valdes slumpmässigt ut från en lista av kända grisgårdar i området. I studie I användes en holistisk metod, nämligen besättningshälsovård. Det är en vanlig metod inom klinisk veterinärpraktik, och i den här studien innebar det månatliga gårdsbesök där intervjuer, observationer, kliniska undersökningar och provtagning användes för att identifiera hälso- och produktivitetsproblem. Genom att använda metoden hittades några sjukdomsrelaterade problem som misstänktes vara viktiga för flera gårdar. Problemen inkluderade parasiter, parvovirus och antibiotikaresistens hos vissa bakterier, och förekomsten av dessa studerades närmare i alla besättningar (studie I+II).

Resultaten visade att det generella hälsoläget och produktiviteten hos grisarna var dålig, men att situationen varierade mellan besättningarna. En sugga producerade i genomsnitt 11 avvanda smågrisar per år, den genomsnittliga dagliga tillväxten hos grisar i åldrarna 0-12 månader var 101 g/dag och dödligheten hos smågrisar, växande grisar och vuxna suggor var 15,1 %, 9,7 % respektive 7,9 %.

De flesta bönder utfodrade inte sina grisar tillräckligt, utan gav för liten mängd och använde ibland ett foder som inte var lämpligt för grisar. Detta resulterade i låg tillväxt hos grisarna, jämfört med grisar på stora gårdar i Europa. Suggorna födde få kullar per år och fick få kultingar per kull. Det kan finnas flera skäl till detta, som t.ex. värmestress, olika bakterie-, virus- eller parasitinfektioner, och dålig utfodring, men det berodde troligtvis också på hur bönderna skötte sina grisar, eftersom många bönder inte visste hur man säkert hittade brunster och när man skulle betäcka suggorna under brunsten.

Många olika sjukdomar hittades, och det vanligaste symptomet var klåda, orsakat av löss och möjligtvis också skabb. Invärtes parasiter såsom mask var vanliga, och det påvisades höga nivåer av parasitägg i grisarnas avföring. De invärtes parasiterna orsakade också diarré hos smågrisar och växande grisar, vilket resulterade i viktminskning och även dödsfall hos några grisar. Allvarlig diarré efter avvänjning sågs i de två största besättningarna, och en sjukdomsframkallande variant av bakterien *E. coli* påvisades. Resistens mot vanligt använda typer av antibiotika såsom tetracyklin hittades också hos bakterierna *E. coli* och stafylokocker från både friska och sjuka djur. Grisar i många besättningar hade antikroppar mot parvovirus, ett virus som kan orsaka dödfödda smågrisar och små kullar, ett problem som också sågs i många besättningar. Ett fåtal besättningar beskrev en allvarlig sjukdom och dödsfall orsakade av vad de trodde var afrikansk svinpest. Det är en vanlig virussjukdom i Uganda, men förekomst av viruset kunde inte påvisas i studien.

Sammanfattningsvis står ugandiska grisbönder inför en mängd hälsorelaterade problem hos sina grisar. Alla delar av den här komplexa situationen måste beaktas när man planerar åtgärder för att förbättra hälsa och produktivitet.

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Appendix. Interview and observation guides

Semi-structured interview guide, first primary visit

Farm identity number:	**Date:**
Interviewer:	

Responder(s) *Underline main*	
1. How many pigs are presently on the farm?	**Total:**
Female adults (Sows/gilts):	Boars:
Weaners/growers/finishers:	Suckling piglets:

Subject
Examples of questions
Examples of information which could be relevant

General

2. General • Tell me about your pig business. • Why did you start raising pigs? • How important are the pigs for your household? • What are your experience with pigs? • Who owns the pigs? • From whom/where do you get information if you have any questions regarding pigs and pig production? *Household's main source of income* *Reason for keeping pigs*	

Importance of the pigs for the household *Experience of pigs* *Ownership* *Source of information* *Other animals on the farm*	
3. Pig management • What are your daily chores with the pigs? Who does them and why? • Show me what you do with the pigs on a daily basis. • What kind of routines do you have with different groups of pigs, for example piglets? • How do you do when you want to buy/to sell a pig? *Daily care* *Buying/selling* *Routine/common treatment; vaccination, castration, deworming, parasite spray, vitamin/mineral booster, antibiotics etc. How, on which pigs, when, how often, drugs used…* *Source of treatment information* *Source of drugs* *Records*	
4. Feed • What do your pigs eat? • Show me what your pigs eat. • How often do you give them feed/do they have access to feed? *Bought/homemade/scavenge/kitchen waste/mix* *Treatment of feed (ex boil)* *Continuous supply/x number per day* *Delivery system* *Volume* *Storage* *Feeding for different group of pigs*	

5. Water • How do your pigs access/get water? • What kind of water do they have access to? • How often do they have access to water? *Tap water/well/borehole/waste water/stream…* *Continuous supply/x number per day* *Delivery system* *Volume* *Storage* *Water for different group of pigs*	
6. Housing • How do you keep your pigs? • How do you constrict movement of your pigs? *Free-range/tethered/Housed/Mix* *Thermal comfort (shade, water, mud, bedding, draft)* *Housing for different groups of pigs* *Bedding material*	
7. Cleaning • Show me how you clean the pig area. • When do you clean the pig area? • How often do you clean the pig area? *Cleaning between litter/routinely/every day/after pigs are sold…* *Removal of manure, water, scrubbing, disinfectants…*	

8. Biosecurity measures • What do you do to keep your pigs from getting sick? • What are your rules if anyone (neighbor, trader, vet) wants to visit your pigs? • What do you do if a pig gets sick? • What do you do if a pig dies? *Quarantine (new or sick pigs)* *Disposal of dead pigs, incl viscera* *Contact with other pigs/indirect contact via people or equipment (shared tools)* *Change clothes/shoes* *Hand hygiene* *Visitors' log* *Other activities in the vicinity of the farm (pork joint, slaughter slab…)* *Fencing* *Sectioning*	
9. Manure • What do you do with the manure from the pigs? *Use or disposal of manure* *Selling/buying*	

Reproduction

10. Heat detection and service • How do you do to get your sow(s) pregnant? • How do you know when a sow needs service/to go to a boar? • When do you service your sow/take it to a boar? • How do you do when a sow needs to be serviced? *Use of heat detection* *How heat is detected* *How often is it controlled* *Planned/not planned service* *AI/Natural boar* *Number of times serviced/during how long* *Own boar/village boar/other* *Take sow to boar/take boar to sow* *Breed and inbreeding*	
11. Gestation • How do you know if a sow is pregnant? • How long is she pregnant? • What do you do when she is pregnant? *Knowledge about gestation* *Special treatment to pregnant sows*	

12. Farrowing • How do you know when a sow is about to farrow? • What do you do when you know a sow should farrow soon or see that she starts to farrow? • How do you handle the newly born piglets? *Surveillance of farrowing* *Bedding material* *Care of neonates*	
13. Recruitment • If you need or want new sows, how do you get them? *Buy new sows/own recruitment of gilts* *How to choose which to buy?* *Status at buying (gilt/sows…)* *From where are they bought?* *How to choose which gilts to keep?*	

Health and constraints

14. Goals What are your goals with your pig business?

15. Constraints What do you think are the major constraints or problems for your pig production?
16. Health issues What do you think are the major health issues or health problems for your pigs?

Semi-structured interview, subsequent primary visits

Farm identity number:	**Date:**
Interviewer:	

Responder(s) *If several, underline main*	
1. General; how is everything going?	
2. How many pigs are presently on the farm?	**Total:**
Adult females (sows/gilts):	Boars:
Growers/finishers:	Suckling piglets:
3. Did you buy or get any new pigs since the last visit?	Yes No
If yes: *How many?* *Which kinds of pigs?* *From where/whom?* *When?* *Why?*	
4. Did you sell, slaughter or give away any pigs since the last visit?	Yes No
If yes: *How many?* *Which kinds of pigs?* *To where/whom?* *When?* *Why?*	

5. Have any of your pigs been sick since the last visit?	Yes No
If yes: *How many?* *Which kinds of pigs?* *When?* *Symptoms?* *Treatment?* *Outcome?*	
6. Did any of your pigs die since the last visit?	Yes No
If yes: *How many?* *Which kinds of pigs?* *When?* *Symptoms before death?* *Reason for death?*	
7. Have you treated any pigs with any drug or local treatment since the last visit?	Yes No
If yes: *Why/symptoms?* *How many and which of pigs?* *What treatment?* *When?* *Outcome?*	
8. Have any of your sows been in heat since the last visit?	Yes No
If yes: *When?* *Which sow(s)?*	

9. Have any of your sows been serviced since the last visit?	Yes	No
If yes: *When?* *Which sow(s)?* *How (AI/natural)?* *Which boar?* *Where did the service take place?*		
10. Have any of your sows farrowed since the last visit?	Yes	No
If yes: *When?* *Which sow(s)?* *How many piglets (live and dead)?*		
11. Have you weaned any piglets since the last visit?	Yes	No
If yes: *How many?* *From which sow(s)?*		
12. *If they have a boar;* has it been used for service since the last visit?	Yes	No
If yes: *How many times?* *With sows on farm or others?* *On farm or somewhere else?*		
13. Has anything else happened in the herd since the last visit that you wish to tell us?		

14. **Have you changed anything about your pigs or the way you keep or tend to them since the last visit?**
Specific update/clarification questions. The subjects for questioning are individual and decided based upon information retrieved on previous visits; need for clarification, update, or missing information relevant to health and productivity issues

Example of observation guide

Farm identity number:	Date:
Observer:	

Subject *Examples of information which could be relevant*	*Observations and impressions from the farm visit. Continue on a blank sheet if more space is needed.*
1. Housing *Difference between groups* *Bedding material* *Size of pens* *Stocking density*	
2. Grounds *Pig area* *Houses* *Storages* *Surroundings* *Other pig businesses*	
3. Cleaning *Possibility to clean* *Evidence of cleaning* *General cleanliness*	

4. Management *Daily care* *Routine treatment* *Difference between group*	
5. Nutrition *Presence of feed* - *Kind of feed, quality, quantity, old feed* *Presence of water* - *Quality, quantity, old water*	

6. Biosecurity *Fencing* *Sectioning* *Tools* *Possibility to wash/disinfect hand/boots/equipment* *Visitors* *Other animals/wild animals in contact/possible contact with pigs* *Contact with environment (bushes etc)* *Human latrines*	
7. Manure *Disposal* *Use* *Handling*	
8. Reproduction *Heat(detection)* *Gestation* *Service* *Farrowing* *Boar*	
9. Drugs *Evidence of drug use* *Which drugs*	
10. Records *Keeping of own records* *Using records for the study*	

11. Animal welfare *Freedom:* *From hunger/thirst* *From discomfort* *From pain/injury/disease* *To express normal behav.* *From fear/distress*	
12. Gender *Difference in answers* *Difference in tasks* *Decision making*	
13. Health *Health issues*	
14. Other	

Structured interview and observation guide for secondary visits

Farm identity number:	**Date:**
Interviewer	

Responder(s) *If several, underline main*	
1. How many pigs are presently on the farm?	**Total:**
Adult females (sows/gilts):	Boars:
Weaners/growers/finishers:	Suckling piglets:
2. Did you buy or get any new pigs since the last visit?	Yes No
If yes: *How many?* *Which kinds of pigs?* *From where/whom?* *When?* *Why?*	
3. Did you sell, slaughter or give away any pigs since the last visit?	Yes No
If yes: *How many?* *Which kinds of pigs?* *To where/whom?* *When?* *Why?*	

4. Have any of your pigs been sick since the last visit?	Yes No
If yes: *How many?* *Which kinds of pigs?* *When?* *Symptoms?* *Treatment?* *Outcome?*	
5. Did any of your pigs die since the last visit?	Yes No
If yes: *How many?* *Which kinds of pigs?* *When?* *Symptoms before death?* *Reason for death?*	
6. Have you treated any pigs with any drug or local treatment since the last visit?	Yes No
If yes: *Why?* *How many and which of pigs?* *What treatment?* *When?* *Outcome?*	
7. Have any of your sows been in heat since the last visit?	Yes No
If yes: *When?* *Which sow(s)?*	
8. Have any of your sows been serviced since the last visit?	Yes No
If yes: *When?* *Which sow(s)?* *How (AI/natural)?* *Which boar?* *Where did the service take place?*	

9. Have any of your sows farrowed since the last visit?	Yes No
If yes: *When?* *Which sow(s)?* *How many piglets (live and dead)?*	
10. Have you weaned any piglets since the last visit?	Yes No
If yes: *How many?* *From which sow(s)?* *When?*	
11. *If they have a boar*; has it been used for service since the last visit?	Yes No
If yes: *How many times?* *With sows on farm or others?* *On farm or somewhere else?*	
12. Has anything else happened in the herd since the last visit that you wish to tell us?	

Observations	
13. How many pigs do you see on the farm?	**Total:**
Adult females (sows/gilts):	Boars:
Growers/finishers:	Suckling piglets:
14. Do any pigs have these signs of disease? Diarrhea, coughing, shivering, discoloration of skin	Yes No
If yes: *Which symptoms?* *How many?* *Which kinds of pigs?*	
Not mandatory **15. Observations of other issues in the questionnaire;** *Selling, deaths, treatments, heat, service, farrowing, weaning*	
16. ***Not mandatory*** **Other observations**	

Pigs are important to smallholder farmers in Uganda as savings and source of income, but their productivity is low. This licentiate thesis investigated the overall health and productivity in Ugandan pig herds by using a holistic approach, *i.e.* veterinary herd health management. The results showed that many factors, such as inadequate feeding, poor reproduction, poor biosecurity, and infectious disease, hamper the production.

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