FACTORS AFFECTING THE DESIGN OF INTEGRATED STRATEGIES FOR THE CONTROL OF *TAENIA SOLIUM* INFECTIONS IN KAMULI AND HOIMA DISTRICTS, UGANDA

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A thesis Submitted in fulfillment of the requirements for the Award of Degree of Doctor of Philosophy in Livestock Production Systems of the University of Nairobi

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February 2022

DECLARATION

This thesis is my original work and has not been presented for a degree in any other university for examination.

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DEDICATION

This thesis is dedicated to my loving parents Mr. Paul Ngwili and Mrs. Esther Wanza who taught me the value of education and the power of prayer.

This work is dedicated to my beloved wife Damaris and my brothers and sisters who have been a constant source of encouragement and support throughout the course of my studies.

I also dedicate this work to my lovely children Jeremy and Keziah, my nieces and nephews. I hope this work will motivate you to pursue your academic goals.

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1. **Ngwili, N**., Johnson, N., Wahome, R., Githigia, S., Roesel, K. and Thomas, L., 2021. A qualitative assessment of the context and enabling environment for the control of *Taenia solium* infections in endemic settings. PLoS neglected tropical diseases, 15, e0009470
2. **Ngwili, N.,** Thomas, L., Githigia, S., Muloi, D., Marshall, K., Wahome, R. and Roesel, K., 2021. Co-infection of pigs with Taenia solium cysticercosis and gastrointestinal parasites in Eastern and Western Ugandahttps://link.springer.com/article/10.1007%2Fs00436-021-07380-9

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LIST OF ABBREVIATIONS

AIC	Akaike Information Criterion
ASF	African Swine Fever
ACIAR	Australian Centre for International Agricultural Research
CSF	Classical Swine Fever
CLTS	Community Led Total Sanitation
ELISA	Enzyme-Linked Immunosorbent Assay
PCC	Porcine Cysticercosis
GLMM	Generalized Linear Mixed Effects Model
GI	Gastrointestinal
NCC	Neurocysticercosis
NAGRIC & DB	National Animal Genetic Resources Centre and Databank
NGO	Non-Governmental Organization
NSCP	National Schistosomiasis Control Programme
WHO	World Health Organization
IACUC	Institutional Animal Care and Use Committee
IREC	Institutional Research Ethics Committee
ILRI	International Livestock Research Institute
ITFDE	International Task Force for Disease Eradication
USD	United States of America Dollar
FBD	Food Borne Diseases
DHO	District Health Officer

DVO	District Veterinary Officer
DALYS	Disability Adjusted Life Years
YLD	Years Lost due to Disability
YLL	Years of Life Lost
LC1	Local Chairman One
LMICs	Low- and Middle-Income Countries
MAAIF	Ministry of Agriculture, Animal Industry and Fisheries
MRI	Magnetic Resonance Imaging
CT	Computed Tomography
SLR	Systematic Literature Review
STHs	Soil Transmitted Helminths
PROSPERO	International Prospective Register of Systematic Reviews
PHAST	Participatory Hygiene and Sanitation Transformation
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
NTDS	Neglected Tropical Diseases
EU	European Union
USAID	United States Agency for International Development
FAO	Food and Agricultural Organization
EPG	Eggs Per Gram
OPG	Oocysts Per Gram
UPG	Uganda Pig Genetics Project
UBOS	Uganda Bureau of Statistics
OIE	World Organization for Animal Health

OR	Odds Ratios
ODK	Open Data Kit
OECD	Organisation for Economic Co-operation and Development
CBOs	Community-Based organizations
MDA	Mass Drug Administration
FGD	Focus Group Discussion
KII	Key Informant Interview
VHT	Village Health Teams

ABSTRACT

Taenia (T.) solium is a zoonotic parasite causing three diseases: - Taeniasis and cysticercosis in humans and porcine cysticercosis in pigs.The life cycle is entirely dependent on the transmission between humans and pigs and therefore, breaking the transmission paths can lead to total elimination of the worms(Gemmell et al., 1983). Different interventions to break the transmission cycle exists and have been trialled in different combinations resulting to varying levels of impact. The success or failure of control interventions tested in different endemic areas of the worldmay be attributed to the consideration or failure to consider the context. In the first part of the study, the contextual factors that may influence the success of interventions in the different endemic settings globally were investigated. Context refers to the features of the circumstances where an intervention is conceived, developed, implemented and evaluated and is made up of several factors here in referred to as contextual factors. In the second part, using Uganda as an example of an endemic country, the epidemiological status of *Taenia (T.) solium* and other pig gastrointestinal parasites as well as the stakeholder knowledge, attitudes, and practices on the control of *T. solium* infections was investigated. The objectives of the study were: -

1. To determine the context and enabling environment for the success of control interventions against *Taenia solium* infections in endemic settings.
2. To determine the epidemiological and coinfection status of pigs with porcine cysticercosis and gastrointestinal parasites in Kamuli and Hoima districts, Uganda.
3. To determine the stakeholders' knowledge, attitudes, and perceptions which may influence the adoption of *T. solium* infections control strategies in Uganda.

To assess the contextual factors and enabling environment influencing the success of interventions across different endemic regions of the world, data were collected through systematic literature

review (SLR) and key informant interviews (KII). The SLR focused on studies that implemented *T. solium* control interventions and was used to identify the contextual factors and enabling environment relevant to successful planning, implementation and evaluation of the interventions. To further highlight the importance and linkage of the contextual factors and control interventions, KII were conducted through skype^{TM} with 11 researchers or implementers of the studies included in the SLR. A cross-sectional study was conducted in Kamuli and Hoima districts to determine the prevalence of *T. solium* infection in pigs and the risk factors, the prevalence and intensity of pig gastrointestinal parasites and the co-infection status. A total of 294 pig sera was collected from 161 households across the two districts and tested for *T. solium* cysticercosis circulating antigens using commercially available Enzyme-Linked Immunosorbent Assay (ELISA) kits. A total of 291 pig fecal samples were also collected and pig parasite eggs identified and quantified using the McMaster slide technique. A household level questionnaire was administered using Open Data Kit (ODK) to collect data on the putative risk factors for infection of pigs with *T. solium* cysticercosis. To further highlight the knowledge, attitudes and practices that may influence *T. solium* control in Uganda, data was collected using focus group discussions (FGD) with pig farmers, community leaders, animal health officers, community health officers and pig/pork traders. Additionally, KIIs were conducted with senior officials in Uganda in the ministries of livestock and health, local non-governmental organizations and private companies promoting pig rearing.

Data analysis and management for the qualitative data was carried out in NVIVO Version 12. For the cross-sectional survey data, both univariable and multivariable analysis were conducted using generalized mixed effect models (GLMM) in R.

The SLR identified 41 publications, globally, that had considerations of the contextual factors. They were grouped into efficacy (10), effectiveness (28) and scale up or implementation (3) research studies. The identified contextual factors included epidemiological, socioeconomic, cultural, geographical and environmental, service and organizational, historical and financial factors. The enabling environment was mainly defined by policy and strategies supporting *T. solium* control. The apparent animal level seroprevalence for PCC was 4.8% (95% CI 2.7 – 7.1) and was different across the two districts (P = 0.018, Fisher exact test). At herd level, the prevalence was 9.7% (5.5 – 14.4). The prevalence of the different nematode eggs and coccidia oocysts in the two districts were as follows: Strongyles 79.0% (95% CI 74.3 – 83.6), Coccidia 73.3% (95% CI 68.3 – 78.6), *Trichuris* spp. 7.4% (95% CI 4.9 – 10.6), *Strongyloides ransomi* 2.1 (95% CI 0.7 – 3.5), *Ascaris* spp. 4.9 (95% CI 2.8 – 7.4). Overall, across the two districts, the arithmetic mean for the oocysts per gram (OPG) for coccidia was 2042.2±5776.1 and eggs per gram (EPG) was highest for strongyles 616.1±991. Overall, 57.4% of the porcine cysticercosis seropositive pigs were also positive for at least one of the gastrointestinal helminths that included strongyles, *Strongyloides ransomi*, *Trichuris* spp. and *Ascaris* spp. The results of multivariable analyses identified the knowledge that pigs could be infected by *T. solium* by eating dirt feeds as a significant predictor of herd-level PCC seropositivity, OR 5.5 (95% CI 0.7 - 43.8) p=0.005. Results from the FGDs with the various stakeholder categories showed that there was differential, limited and fragmented knowledge levels on *T. solium* infections among stakeholders. Pig farmers, community leaders and pig/pork traders had almost no knowledge and was confounded by knowledge on other worm infections in pigs and humans. Deworming of children was well received but was mainly pushed by government programs that were supported by international donor agencies. Pig confinement, pit latrine construction, coverage, maintenance and sustained use was determined by the cultural, socio-economic and physical or environment factors of the target population and area. Mass drug administration for school children and adults, vaccination of pigs with TSOL18 vaccine plus treatment with oxfendazole and health education were widely acceptable to the local stakeholders but with conditions needed for their successful adoption including subsidization of the prices for the vaccine and dewormer as well as proper sensitization and wide coverage for the programme.

The effect of contextual factors on efficacy, effectiveness and scale-up studies varies and the factors that include - epidemiological factors, socioeconomic and cultural factors, geographical and environmental factors, service, and organization factors interact to influence the implementation and outcomes of *T. solium* control projects. Knowledge that pigs can get infected by eating dirty feeds was found to be a significant predictor for *T. solium cysticercosis* seropositivity at household level. The prevalence for infection with any gastrointestinal parasite was high and similar across the two districts. There was also a high likelihood of infection of pigs with multiple helminth infections and PCC. Knowledge does not always translate to practice and therefore innovative ways of triggering change of practice may be necessary including incentives and dis-incentives to reinforce good practices and deter negative practices. Further studies are required to test the feasibility of use of oxfendazole and cost benefit analysis in the control of *T. solium* cysticercosis and some of the gastrointestinal worms in pigs.

CHAPTER ONE

GENERAL INTRODUCTION

1.1 Background information

The livestock sector increasingly drives the world food economy due to the shift in income, diet and food consumption patterns towards livestock products (FAO, 2010; Thornton, 2010).The sub-Saharan Africa region accounts for approximately 13% of the global population and is projected to increase to 22% by 2050 (OECD-FAO, 2016). Uganda's population was projected to be 41.6 million with over 10 million people living in urban centres by mid-2020 (UBOS, 2020).Rapid population increase coupled with megatrends such as raising middle class, rapid urbanization and shift in diet preferences has created increased demand for animal source foods (ASF)(Herrero et al., 2014; OECD-FAO, 2016).

Pig production is one of the fastest growing livestock sectors worldwide and this trend is expected to continue over the coming years(FAO, 2011). Growth in the sector is mostly happening in low- and middle-income countries (LMIC) where pig production is gaining importance due to the growth of economies of these countries, lack of grazing lands and the quick turnaround from pig farming(FAO, 2019). In the Eastern and Southern Africa region, pig production has increased significantly especially in rural communities where production is predominantly by smallholder and resource-poor farmers, characterized by a free-range management system(Herrero et al., 2014; Phiri et al., 2003).

In Uganda, production and consumption of livestock and livestock products has been growing rapidly with greatest growth observed in the pig sector (Tatwangire, 2014). Uganda's pig population was estimated to be 3.2 Million pigs in 2008 with the central region contributing 41%

of the population(MAAIF and UBOS, 2008). The pig sector is generally underdeveloped although it has high potential for growth, given the rising demand for pork domestically, and in neighbouring countries such as South Sudan, Rwanda and the Democratic Republic of Congo (Ouma et al., 2017).

The most common pig production systems in Uganda are semi-intensive and extensive production systems. In the semi-intensive system, pigs are partly housed and partly kept outdoors on pasture. The extensive production system is characterised by pigs kept out-door, to freely move around the homestead as they feed on their own, or tethered (Tatwangire, 2014; Roesel *et al.*, 2017). The raising of pigs extensively combined with poor sanitary conditions predisposes them to *Taenia (T.) solium* infections (Phiri et al., 2003).

T. solium taeniasis/cysticercosis is classified as a neglected tropical disease, a group of transmissible diseases that are found in tropical and subtropical conditions in 149 countries, affecting over one billion people in impoverished and marginalized communities and exerting high costs on the economies of developing countries every year (WHO, 2018).*T. solium* is a zoonotic parasite with humans as the definitive host, harbouring the adult tapeworms in the small intestines, an infection acquired by ingesting undercooked pork infected with *T.solium* larvae (*cysticercus cellulosae*)(CDC, 2013). Once the larvae develop into adult tapeworms, tapeworm eggs are shed by infected humans through faeces; and subsequently gets ingested by pigs as they scavenge in places where open defecation is practised (García et al., 2003; Phiri et al., 2002). Humans can be aberrant intermediate hosts if they ingest tapeworm eggs from the environment resulting to neurocysticercosis (NCC) when the cysts lodge in the central nervous system (García et al., 2003).

T. solium causes three diseases with varying degrees of severity and requiring different approaches for control. Neurocysticercosis is known to be one of the major parasitic diseases which pose a serious public health concern due to its social consequences(Carpio et al., 2018). This is mostly as a result of seizures, and consequently, stigmatization and incapacitation leading to decreased work productivity (Carpio *et al.,* 1998; Carabin *et al.,* 2005; Carpio *et al.,* 2018). Taeniasis can lead tohuman weight loss and nutrition deficiency, especially in children due to infestation of the small intestine with the worms.

Porcine cysticercosis (PCC) on the other hand, does not cause clinical symptoms in pigs but may result in condemnation of pig carcasses, potentially reducing the household income of farmers, many of whom are women (Colley, 2000;Carabin *et al.,* 2005). Thus, the diseases are important constraints for improving the lives and livelihoods of especially smallholder pig farming communities. The control of *T.solium* infections may involve one or a combination of the following options; human treatment, pig vaccination and treatment, improvement of meat inspection and proper cooking of meat, health education, and improvement of hygiene and sanitation (Gabriel et al., 2017).

1.2 Problem statement

The World Health Organization's World Health Assembly in 2013, called for action to prevent, control, eliminate or eradicate NTDs including *T. solium* cysticercosis by 2020(WHO, 2013). The 2020 milestone of having scaled up interventions against *T. solium* infections in selected countries has not been met(WHO, 2013). The updated 2021-2030 roadmap now provides specific targets for a number of countries with "intensified control in hyperendemic areas" and calls for concerted efforts among stakeholders (WHO, 2020).

T. solium causes severe human disease and results in important economic losses. It is also clear that the infections are eradicable due to the existence of several control options focusing on human treatment, pig vaccination and treatment, health education, or sanitation which have been found to be effective. Despite the availability of various control strategies, the diseases remain largely uncontrolled in many endemic regions including Uganda.

Failure of the interventions to achieve expected impact could be attributed to failures in addressing the various contextual factors or creating an enabling environment needed to underpin success. Contextual factors in this instance are features of the circumstances under which an intervention is conceived, developed, implemented and evaluated whilst an enabling environment encompasses supportive legal and policy frameworks and a variety of institutional structures. There is information gap on the type of contextual factors which might have influenced the success or failure of control interventions tested in different endemic areas of the world. Specifically, there is limited information on the contextual factors in endemic areas of Uganda including the local stakeholders' socioeconomic and cultural characteristics that may influence the adoption of *T. solium* Control strategies and the acceptability and feasibility of some of the interventions which have worked in other endemic regions. The opportunities available for integrated control in Uganda have also not been studied.

1.3 Research questions

The research questions addressed by the current study are: -

1. What contextual factors have contributed to the success or failure of *T. solium* control interventions implemented in different endemic areas of the world?
2. What is the epidemiological and coinfection status of pig with *T. solium* and gastrointestinal parasites in Kamuli and Hoima district, Uganda?
3. What is the current stakeholders' knowledge, attitudes, and perceptions which may influence the adoption of *T. solium* infections control strategies in Uganda?

1.4 Objectives

1.4.1 Broad objective

The overall objective of the study was to generate evidence on the contextual factors to support successful implementation and adoption of *Taenia solium* Control strategies in Uganda

1.4.2 Specific objectives

1. To determine the context and enabling environment for the success of control interventions against *Taenia solium* infections in endemic settings.
2. To determine the epidemiological and coinfection status of pigs with porcine cysticercosis and gastrointestinal parasites in Kamuli and Hoima districts, Uganda.
3. To determine the stakeholders' knowledge, attitudes, and perceptions which may influence the adoption of *T. solium* infections control strategies in Uganda.

1.5 Justification

T. solium is the top food-borne zoonotic parasite contributing 2.8 million Disability Adjusted Life years (DALYs) globally; most of the burden is related to human neurocysticercosis (NCC) as an important cause of late onset epilepsy (Havelaaret al., 2015; WHO, 2014b). Porcine cysticercosis (PCC) leads to high economic losses due to condemnation of cyst infested carcasses or the sale of the carcasses at reduced prices. This has been estimated to result to losses of up to 25 million USD in West and Central African countries (Zoli et al., 2003). Although theoretically controllable and declared eradicable by the International Task Force for Disease Eradication (ITFDE) (ITFDE, 1993),the infections remains uncontrolled and neglected in most endemic countries possibly due to lack of well-defined control algorithms, estimates for their cost-effectiveness in endemic areas and the failure to consider the context underpinning implementation (Braae et al., 2019).

The determination of the right combination of control interventions to use against *T. solium* will require a clear understanding of the context in which intervention will be implemented including the epidemiological aspects of the diseases and the socioeconomic and cultural characteristics of the target communities as well as available opportunities for integrated control. This study aims to fill this information gap for Uganda by identifying contextual factors which have affected the implementation and evaluation of *T. solium* control intervention in other endemic areas. The contextual factors operating in the study sites in Uganda will be determined including stakeholders' characteristics that may influence successful implementation of control intervention. The acceptability and feasibility of some control interventions that have been implemented in other endemics settings will be determined as well as the opportunities available for integrated control of the parasite.

CHAPTER TWO

LITERATURE REVIEW

2.1 Taenia solium

Taenia solium is a helminth species in the Class Cestoda, Family Taeniidae and in the Phylum Platyhelminthes which are the flatworms (Schantz, 1996). *Taenia spp.* which have human definitive hosts, utilize domesticated animals as the intermediate hosts (Hoberg et al., 2001). The genus *Taenia* has about 20 species; most important of these to human health are the zoonotic tapeworms*. solium* (pork tapeworm), *T. saginata* (beef tapeworm) and *T. hydatigena* (canine tapeworm) (Pawlowski, 2002). The morphological structures of the tapeworm consist of a scolex, a neck, and segmented (proglottids) body. The scolex is equipped with suckers and/or hooks which are used to attach to the host's small intestines(Schantz, 1996). The worms can have up to 1,000 proglottids (segments) each containing at least 50,000 eggs when mature(CDC, 2020).

2.1.1*Taenia solium* life cycle

The life cycle of *T. solium* involves a species-specific survival pattern of transferring to specific intermediate host, which then are transferred to a definite (human) host (Hird & Pullen, 1979). The pig is the obligatory intermediate host while humans serve as the definitive hosts for *T.solium* (Brutto, 2013; Hoberg et al., 2001)(Figure 1). *T. solium* infections result in three diseases, namely: taeniasis (in humans), neurocysticercosis (NCC, in humans) and porcine cysticercosis (PCC, in pigs) (Carabin et al., 2011; García et al., 2003) as outlined in sections 2.1.2, 2.1.3 and 2.1.4.

2.1.2 Disease 1 – Taeniasis

Humans are the only known definitive host (final host) of the adult stage of *T. solium*. Infection is acquired by ingesting undercooked pork infected with viable *Taenia* larvae (cysticerci) (CDC, 2013). The cysticerci evaginate in the walls of the small intestines, where they mature into adult worms measuring 2-7 metres in length and causing taeniasis (CDC, 2013). When mature, gravid proglottids are detached from the distal end of the worm and are passed out of the human body with the feces, liberating thousands of fertile eggs to the environment (Carpio et al., 1998; WHO, 2014b). The proglottids are motile and as they crawl, they release the thousands of eggs they carry. Taeniasis is usually asymptomatic but at times abdominal distress, dyspepsia, increase appetite, nausea, localized pain, and diarrhea may result (Heyneman, 1996).

2.1.3 Disease 2 – Porcine cysticercosis (PCC)

The intermediate host for *T. solium* is the pig, which is infected by ingesting parasite eggs or proglottids containing eggs from the environment (e.g., when people with taeniasis defecate in the open) and free-ranging pigsingest stools containing *T. solium* eggs. (García et al., 2003). When ingested, the oncospheres are released from the eggs and penetrate the intestinal mucosa, migrate through the bloodstream and lodge in tissues. Over a period of 2-3 months, they evolve into larvae that enlarge and mature into a metacestode (cysticerci) (Carpio et al., 1998;García et al., 2003) which lodge in the muscles and subcutaneous fat layer. This condition is referred to as porcine cysticercosis(PCC)(García et al., 2003).

2.1.4 Disease 3 – Neurocysticercosis (NCC)

Humans can also be accidental intermediate hosts of *T. solium* after ingesting its eggs from contaminated vegetables or fruits or by the fecal-oral route (ingestion of eggs from contaminated hands) in individuals harboring the adult parasite in the small intestine resulting to human cysticercosis(García et al., 2003). The cysticerci can lodge in the muscle but have a particular tropism to neurological tissue including the brain and eyes. When the cysticerci lodge in the brain and depending on where in the brain they lodge, they can cause headaches, epileptic seizures, blindness, mental disturbance and even death (Cruz et al., 1989b; White, 1997). This condition is called neurocysticercosis (NCC)which is considered to be the most common preventable cause of epilepsy in the developing world(Willingham and Engels, 2006).

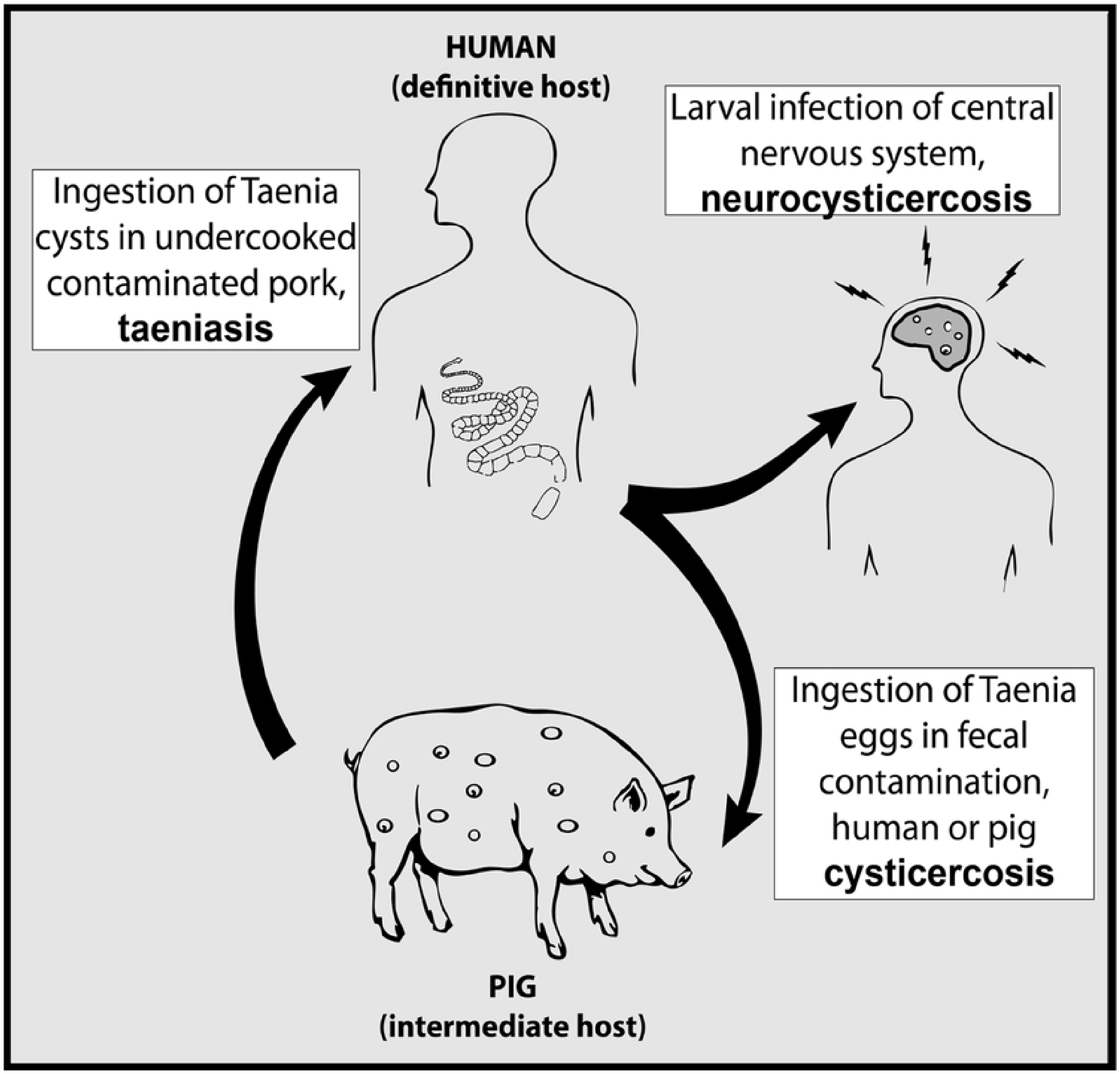

Figure 2. 1: ***Taenia solium*** **life cycle, Source: (O’Neal et al., 2014) * permission was sought and granted from the original authors.**

2.2 Health and economic impacts of *Taenia solium* infections

2.2.1 Health impacts of the diseases

The total global burden of food borne diseases (FBD) caused by *T. solium* due to epilepsy was estimated to be 2.8 million Disability Adjusted Life Years (DALYs) with the burden highest in Africa (WHO, 2017; Havelaar et al., 2015). DALY is metric that allows for the measurement of the gap between current health status and an ideal health situation where the entire population lives to an advanced age, free of disease and disability. It is calculated as the sum of the Years of Life Lost (YLL) due to premature mortality in the population and the Years Lost due to Disability (YLD) for people living with the health condition or its consequences (WHO, 2021a). The DALYs attributed to *T. solium* are of a similar magnitude as the burden due to diarrheal disease agents particularly non-typhoidal *Salmonella enterica*, which is responsible for 4.0 million DALYs and has received more global attention in terms of dedication by governments and other partners to the control than *T. solium*(Havelaar et al., 2015).

It is estimated that *T. solium* infections both taeniasis and NCC affect over 50 million people globally and result in approximately 50,000 deaths per year mostly due to NCC (Schantz et al., 1993). Over 80% of the people affected by epilepsy live in low and middle income countries with 1.90 to 6.16 million of these being from sub-Saharan Africa (WHO, 2021b; Winkler, 2012). Globally, *T. solium* cysticercosis in humans is under-estimated, like other neglected tropical diseases, due to marginalization which allows the parasite to thrive due to poor sanitary and pig husbandry practices (Carabin et al., 2009), poor health care coverage, non-functioning disease surveillance systems and lack of reliable diagnostics techniques (Murrell, 2013).

The health burden due to NCC has been estimated for several African countries. In Mbulu District, Tanzania, NCC imposed an average of 2.73 DALYs per 1000 population per year (Mwang'onde et al., 2014). In 2012 Trevisan et al. (2017) estimated the number of DALYs per 1000 person-years for NCC-associated epilepsy to be 0.7 in Mozambique. In west Cameroon the average number of DALYs was 9.0 per 1000 persons per year (Praet et al., 2009). The human health and economic burden of *T. solium* infections have not been estimated for Uganda but the presence of the infections in humans and pigs is an indicator of burden (Kungu et al., 2017).

2.2.2 Economic impacts NCC and PCC

T. solium cysticercosis imposes a huge financial burden in the different endemic regions and has been estimated for some of the African countries. Carabin used Monte Carlo simulations to estimate the economic impact of *T.solium* infections in South Africa and reported the monetary burden to be between USD 18.6 and 34.2 million with the agricultural sector contributing an average of USD 5.0 million (Carabin et al., 2006). In Cameroon, Praet estimated the total annual costs due to *T. solium* cysticercosis to be USD 12 million with losses accruing to pig husbandry (carcass condemnation and rejection by traders) contributing 4.7% and 95.3% being due to losses caused by human cysticercosis. In Tanzania, total annual cost due to NCC and PCC was USD 3.96 million with NCC contributing 56.8% (Mwang'onde et al., 2014). Similarly, Trevisan and colleagues estimated that USD5 million were spent due to NCC-associated epilepsy and nearly USD3 million were potentially lost due to porcine cysticercosis (Trevisan et al., 2017). In Mozambique, annual total costs due to *T. solium* cysticercosis were estimated at USD 90,000 with NCC contributing 72% and pig production losses contributing 28% (Trevisan et al., 2018). The annual losses in ten west and central African countries was estimated to be about USD29 million with the financial losses due to NCC being hard to estimate although the societal impact of the disease was high (Zoli et al., 2003). Similar observation were made by Carabin et al. (2006) and

Praet et al. (2009) who noted that the social impact due to NCC such as stigma of epilepsy is not taken into account when estimating the costs.

2.3 Epidemiology of *Taenia solium*

2.3.1 Occurrence and global distribution of *Taenia solium* infections

T. solium taeniasis and cysticercosis, both porcine cysticercosis (PCC) and neurocysticercosis (NCC), are endemic in Latin America, India, Asia, and Africa (WHO, 2016)(Figure 2.2). Neurocysticercosis is the common type preventable epilepsy in LMICs with 30% of cases attributed to *T. solium* (Ndimubanzi et al., 2010; WHO, 2021b).

Although, *T. solium* is globally distributed, it is not endemic in high-income countries and in countries where pork is not consumed (Laranjo-Gonzalez et al., 2017). However, *T. solium* cysticercosis is an emerging public health concern in Europe and the USA due to migratory movements from endemic countries (Devleesschauwer et al., 2017; Gabriël et al., 2015)A meta-analysis conducted by Coral-Almeida et al. (2015) estimated the pooled prevalence of *T. solium* antigens to be 4.08% for the Americas and 3.98% for Asia. The pooled seroprevalence of *T. solium* antibodies was 13.03% for Latin America and 15.68% for Asia (Coral-Almeida et al., 2015).
In Africa the *T. solium* antigens and antibodies prevalence was estimated at 7.30% and 17.37% respectively, through a meta-analysis of studies from Africa (Coral-Almeida et al., 2015).*T. solium* is found in much of sub-Saharan Africa and had emerged as a serious problem this region due to increasing popularity of rearing pigs and consuming pork(Phiri et al., 2003). In eastern Africa, the disease has been reported in Tanzania, Kenya, Uganda, Burundi and Rwanda but may be under-reported in both humans and pigs (Waiswa et al., 2009).
In West and Central Africa *T. solium* cysticercosis has been studied particularly in Cameroon (Assana et al., 2010; Pouedet et al., 2002), Zambia (Sikasunge et al., 2007), Mozambique (Afonso

et al., 2011) and Burkina Faso (Carabin et al., 2009). In recent years PCC and HCC have been reported in Tanzania (Braae, Magnussen, & Lekule, 2014;Kabululu et al., 2015) and has been extensively reviewed Ngowi et al. (2019) and in southern African countries (Krecek et al., 2008; Phiri et al., 2003). The prevalences of the three diseases caused by *T. solium* infections in selected countries in sub-Saharan African have been summarized in Table 2.1 and 2.2.

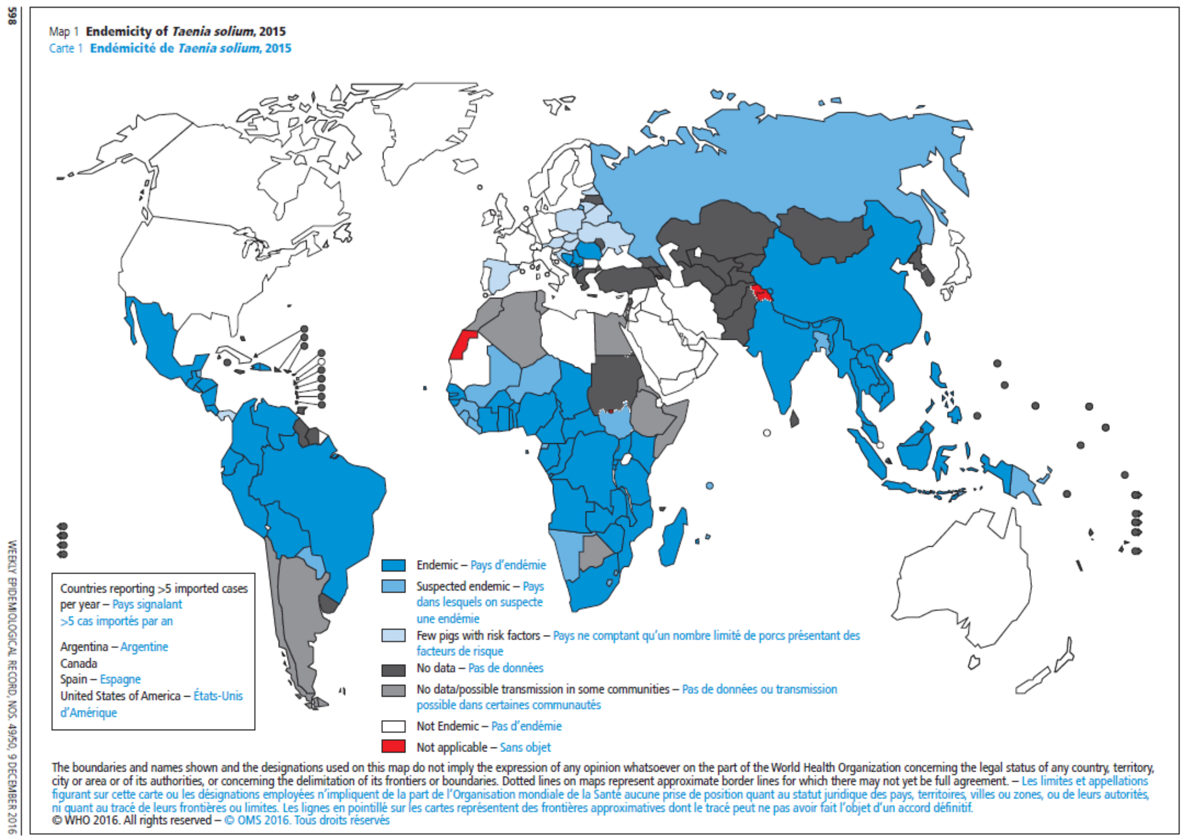

Figure 2. 2:Endemicity of *T. solium* Source (WHO,2015) * The figure was published under creative commons licence which allows reuse with acknowledgement.

Table 2. 1: Prevalence of Taeniasis in some sub-Saharan Africa (Updated from (Assana et al., 2013) and (Braae et al., 2015) *

Country	Prevalence	Target population	References
Kenya	6.74[a]	villagers (n= 386)	(Nguhiu et al., 2018)
Uganda	0.7[a]	Primary school pupils (n= 5313)	(Kabatereine et al., 1997)
Tanzania	0.01[b] 4.1[d]	Villagers (n=1057), Villagers (n= 820)	(Eom et al., 2011) (Mwanjali et al., 2013)
Burundi	0 - 1[a]	School children (n=13841)	(Newell et al., 1997)
Rwanda	0.3[c]	School children (n= 680)	(Soto et al., 2021)
DR Congo	0.37[a]	Villagers (n=816)	(Kanobana et al., 2011)
Ethiopia	1.4[a] 1.3[a]	School children (n=419) Food handlers (n=384)	(Terefe et al., 2011) (Abera et al., 2010)
Cameroon	0.0	Community members (n= 3109)	(Nkouawa et al., 2017)
Zambia	6.3[d]	Villagers (n =708)	(Mwape et al., 2012)
Namibia	0.9[a]	Hospital patients	(Evans & Joubert, 1989)
Mozambique	0.4[a]	Children (0-15 years) n=269	(Noormahomed et al., 2003)
Togo	0.09 - 0.26[a]	Village members (n=1170)	(Dumas et al., 1989)
Madagascar	0.75[a]	Hospital patients (n=401)	(Buchy, 2003)
South Africa	18[a*]	Household toilets	(Trönnberg et al., 2010)

[a] Based-on microscopy, [b] PCR, [C] Microscopy and Copro Ag ELISA, [d]Copro Ag-ELISA

*Household based prevalence

*The prevalences of Taeniasis had been summarized previously by (Assana et al., 2013) and (Braae et al., 2015), the current study updated the table by adding the recent publications.

Table 2. 2: Prevalence of human and porcine cysticercosis in some sub-Saharan Africa (Updated from Assana et al., 2013)*

Country	Porcine cysticercosis		Human cysticercosis	
	Prevalence in pigs	**References**	**Prevalence in humans**	**References**
Kenya	32.8[a] ,5.6[b]	(Eshitera et al., 2012)	3[a]	(Ngugi et al., 2013)
	14[b]	(Githigia et al., 2007)	2.4 – 5[a]	(Waruingi et al., 2002)
	4[a]	(Kagira et al., 2010)		
	6.5[b]	(Mutua et al., 2007)		
	34.4[b],37.6[a]	(Thomas et al., 2016b)		
	4.4[a]	(Akoko et al., 2019)		
Uganda	33.7[b]	(Anyanzo, 1999)	10.3[a]	(Ngugi et al., 2013)
	25.7[a]	(Nsadha et al., 2014)		
	4 -12[b]	(Nsadha et al., 2010)		
	8.6[a]	(Waiswa et al., 2009)		
		(Kungu et al., 2017)		
	10.8 – 17.1	(Nsadha et al., 2021)		
	16.2[c]			
Tanzania	17.4[b]	(Ngowi et al., 2004)	16.7[a]	(Mwanjali et al., 2013)
	7.6 – 16.9[b]	(Boa et al., 2006)	14.8[a]	(Ngugi et al., 2013)
	5.9[b]	(Mkupasi, Ngowi, & Nonga, 2011)		
	11.7[b], 32[a]	(Komba et al., 2013a)		
	15[a]	(Braaeet al., 2014)		
		(Ngowi et al., 2008)		
	32[b]	(Kabululuet al., 2020)		
	9.2[c]			

Table 2.2 continued.				
Country	**Porcine cysticercosis**		**Human cysticercosis**	
	Prevalence in pigs	**References**	**Prevalence in humans**	**References**
Burundi	2 – 39[d]	(Newell et al., 1997)	[e]4.9, [f]58.7, [a]31.5 in epileptic patients	(Newell et al., 1997) (Prado-Jean et al., 2007)(Nsengiyumva et al., 2003)
Rwanda	[b]4	(Mushonga et al., 2018)	21.8 by immunoblot	(Rottbeck et al., 2013)
DR Congo	[b]38.8	(Praet et al., 2010)	[a]21.6	(Kanobana et al., 2011)
Cameroon	[a]24.6, [a]11.0, [a]27.7	(Assana et al., 2010)(Pouedet et al., 2002), (Shey-Njila et al., 2003)	[a]5	(Elliott et al., 2013)
Zambia	[a]30.0-51.7 [b]7.7, [d]47.7 [a]20.8, 9.3 [a]23.3	(Sikasunge et al., 2007) (Phiri et al., 2006) (Phiri et al., 2002) (Sikasunge et al., 2008)	[a]5.8 12.2% to 14.5%	(Mwape et al., 2012) (Mwape et al., 2013)
Mozambique	[b]34.9 [a]5.1	(Pondja et al., 2010) (Pondja et al., 2012)	[e]10.2 12.1	(Noormahomed et al., 2014)(Vilhena et al., 1999)
South Africa	[a]40.6	(Krecek et al., 2008)	[a]10.3	(Ngugi et al., 2013)

[a]Ag ELISA, [b]Tongue palpation, [c]Necropsy, [d]Meat inspection, [e]Enzyme-linked electroimmunotransfer blot assay (EITB), [f]Ab ELISA

*The prevalences of Taeniasis had been summarized previously by (Assana et al., 2013), the current study updated the table by adding the recent publications.

2.3.2 Prevalence of porcine cysticercosis in Uganda

PCC is a significant problem affecting smallholder pig production and the wellbeing of smallholder farming communities and poses a serious public health risk for the general population (Phiri et al., 2003). *T. solium* is prevalent in Uganda but the distribution has not been reported in all areas of the country, but several studies exist and were synthesized in Kungu et al. (2017). The national apparent seroprevalence of 12.2% has been reported by Kungu et al. (2017), although a higher prevalence of 25.7% was reported from specific areas such as Lake Kyoga basin(Nsadha et al., 2014). In a rural survey conducted in Moyo, Northern Uganda in 1999,34-45% of the pigs slaughtered in selected villages were infected(Phiri et al., 2003). In Kamuli and Kaliro Districts, 8.5% of 480 pigs screened were seropositive for the parasite by B158/B60 Ag-ELISA (Waiswa et al., 2009). Kisakye & Masaba (2002) reported that overall, 9.4% of the pigs surveyed were found positive with 33.7% of pigs coming from Lira District being infected. A prevalence of 18.0% was reported in Soroti District by tongue palpation and carcass post-mortem examination(Zirintunda & Ekou, 2015). The prevalence of PCC has not been studied for Hoima District and the previous study in eastern region focused on the larger Lake Kyoga region not Kamuli District specifically.

2.3.3 Prevalence of taeniasis in Uganda

A school-based study on intestinal parasite infections carried out on 5,313 pupils from 98 primary schools in Kampala, reported that *Trichuris trichiura* (28%), *Ascaris lumbricoides* (17%) and hookworms (12.9%) were common infections among the children. *T. solium* was reported as less common (0.7%) parasite together with *Schistosoma mansoni*, *Strongyloides stercolaris*, *Enterobius vermicularis*, *Giardia lamblia*, *Entamoeba coli* and *E. histolytica*. This was after two rounds of mass treatment with praziquantel and albendazole (Kabatereine et al., 1997). Another study on, 66 samples from Mulago hospital in Kampala reported a taeniasis prevalence of 0.5% using direct microscopy and modified Ziehl-Neelsen method (Buzigi, 2015).

2.3.4 Prevalence of neurocysticercosis in Uganda

There are variations in prevalence of active epilepsy across sub-Saharan Africa as shown by a study conducted in Uganda, Kenya, Ghana, Tanzania and South Africa (Ngugi et al., 2013). The study reported that the risk factors due to parasitic infections were more strongly associated with active convulsive epilepsy in adults as compared to children and this was particularly for adult-onset of the disease (Ngugi et al., 2013). In a study focusing on onchocerciasis 33.3% of excised nodules in Moyo and Kanungu Districts, Uganda turned out to be cysts of *T. solium.* The authors observed that maybe the main cause of "onchocerciasis-associated epileptic seizures" in many onchocerciasis endemic communities that have been causally linked to onchocerciasis may actually be due to *T. solium* cyst infection (Katabarwa et al., 2008). In three Northern Uganda districts, the prevalence of HCC among epileptic patients was found to be 15% by Ab ELISA, 13% by immunoblot and 9% by Ag ELISA (Alarakol et al., 2017).

2.4 Risk factors of *T. solium* taeniasis, porcine cysticercosis and neurocysticercosis

The drivers responsible for the occurrence of *T.solium* infections in humans and pigs are poor hygiene and sanitation practices in humans, raising pigs by free-range and tethering, lack of awareness about the disease and its transmission, lack of inspection of pigs before or after slaughter and age of pigs and have been reported in different combinations (Coral-Almeida et al., 2015; Garcia et al., 2003; Murrell et al., 2005). The important risk factors associated with PCC were lack of latrines as identified by (Eshitera et al., 2012; Kagira et al., 2010; Mutua et al., 2007; Ngowi et al., 2004); free range pig husbandry (Pondja et al., 2010; Sikasunge et al., 2007) and pigs being older (Pondja et al., 2010). Risk factors for NCC include pork consumption as identified in Burkina Faso (Carabin et al., 2009)and Burundi (Prado-Jean et al., 2007); being a male (Mwanjali et al., 2013; Prado-Jean et al., 2007) in Tanzania, being aged over 70 years (Kanobana et al., 2011) in Congo DRC and water source (Mwanjali et al., 2013). However, the presence of pig and consumption of pork has not been associated with NCC in Africa as was the case in Latin America (Coral-Almeida et al., 2015).

2.4 1 Consumption of infected pork

Predisposing factors for the transmission of *T. solium* taeniasis include the lack of meat inspection in villages and nearby urban centres, and the low awareness in the local population and among human medicine doctors and veterinarians, of the risks of eating pork with viable *T. solium* cysts (Praet et al., 2009; Phiri et al., 2003). Lack of inspection of pork from home slaughtered pigs has also been cited as a contributing factor. For many years, formal pig carcasses inspection in Uganda was only carried out at Wambizzi abattoir which supplies pork to the urban and peri-urban areas of Kampala (Kisakye & Masaba, 2002). Other regional pig abattoirs with meat inspection have been emerging in Central Uganda over the past five years (personal comm. Kristina Roesel).

Other studies have reported that most of the pork consumed in the countryside is not inspected. A study in the Lake Kyoga region found 90% of the pork consumed was not inspected at all (Nsadha et al., 2014). Under-cooking of pork is also common in rural pork joints and those pork roasting centres along the road side and this increases the risk of ingesting viable cysts (Kisakye & Masaba, 2002) and developing into adult *T. solium* causing taeniasis.

2.4.2 Pig and human exposure to *T. solium* eggs from infected humans

Pig exposure to infective human faeces due to defecation in the open and free roaming pigs is a risk factor for PCC (Ngowi et al., 2004; Sikasunge et al., 2007). In Uganda pigs are reared under free range, intermittent free range or tethering depending on season, with a few intensive pig keeping units (Nsadha, 2013; Dione et al., 2014) and this was found to be a risk factor for PCC (Nsadha et al., 2010). In a study in Lake Kyoga region, Nsadha et al. (2014) reported that only 2% of pigs were confined and during the cropping, growing and harvesting season, most of the pigs (80%) are intermittent free range or tethered some of the time. Tethering was done on the pasture/bushes where people can find privacy to defecate. In Soroti District 48% of the pigs were under tethered, 46% were on free range and only 6% were kept intensively (Zirintunda & Ekou, 2015).

2.4. 3 Pig production systems in Uganda

In Uganda pig production systems can be categorized into three basic production systems: (i) intensive production system where pigs are kept housed all the time and provided with feeds, water, and protection from extreme weather; (ii) semi-intensive production system, where pigs are partly housed and partly kept outdoors on pasture, and; (iii) extensive production systems where pigs are kept out-door, to freely move around the compound and farm as they scavenge for feed on their own, or tethered (Tatwangire, 2014). The FAO classifies pig production system under the landless monogastric production systems where feed is introduced from outside thus the decision regarding feed use and feed production are separated(Steinfeld & Macki-Hokkonen, 1995).

The most important challenge to intensive pig production in developing countries is housing because when the pigs are enclosed the farmer has to provide all the nutrients (Lekule & Kyvsgaard, 2003). The challenge of provision of feeds is further exuberated by the fact that there is high cost of building material such as iron sheets and timber and farmers lack the capital for these investments particularly in the case of Uganda (Muhanguzi et al., 2012). The pigs are housed near the dwelling houses. Four different housing systems are found in Uganda which include pens with wooden (slatted) floors elevated above the ground, tethered pigs majorly close to the house, pens made of wood or stone placed directly on the ground which in most case have dirt floors and pens with concrete floor(Dione et al., 2014;Nissen et al., 2011). The pigs are mainly fed different kinds of kitchen leftovers, grass, potato vines, yams leaves, and sorghum. Commercial feed are hardly used (Nissen et al., 2011).

2.4.4 Open defecation and drinking of unsafe water

Poor disposal of human faeces provides the infective material for porcine cysticercosis if the faeces are contaminated with *T. solium* eggs (Carpio et al., 1998). Open defecation is common in many parts of Uganda and is a risk factor for porcine cysticercosis and neurocysticercosis. Studies have shown that many households did not have latrines thus the household members relieve themselves in the bushes. In Soroti District, 54% of households did not have latrines (Zirintunda & Ekou, 2015). In the Lake Kyoga basin 36% of households studied did not have latrines. Commitment to of use latrines was another common aspect whereby 38% of the latrines were not being used even if they were available (Nsadha et al., 2014). Similar observations have been reported in Cameroon (Assana et al., 2010). Lack of safe clean drinking water resulting in fetching water from rivers, swamps, wells, lakes may increase the risk of ingesting *T. solium* eggs since infectious materials contained in can flow into water sources during rainy season (Nsadha et al., 2014). Source of water was found to be significantly associated with PCC in Uganda (Kungu et al., 2017). Open defecation has also been identified as a risk factor for porcine cysticercosis in studies in Uganda (Alarakol et al., 2021; Nsadha et al., 2010).

2.4.5 Personal hygiene (washing hands after defecation and washing fruits and vegetables)

Poor hygiene practices such as not washing hands with soap after visiting the latrines/toilets and before eating food, eating unwashed fruits and vegetables, and drinking unboiled or untreated water can lead to humans ingesting the eggs of *T. solium* (Kungu et al., 2017). Faeces deposited in the open environment can be washed into unprotected springs and wells posing a risk to both pigs and humans (Bulaya et al., 2015).

2.5 Diagnostic methods in *Taenia solium* epidemiological and interventions studies

An important aspect of *T. solium* control intervention is the measurement of outcomes and evaluation of impact which can be measured through reduction of incidences of human cysticercosis. This can be indirectly measured through reduction in incidences of taeniasis and porcine cysticercosis (Lightowlers et al., 2016) using different diagnostic methods. Diagnostic methods are also required for prevalence studies to provide baseline epidemiological information and spatial distribution of infections (Schantz & Sarti-Gutierrez, 1989).The most important attribute of any diagnostic method used to assess *T. solium* control efforts is specificity(Lightowlers et al., 2016). Low specificity has been established for some of the *T. solium* infection tests, but some have been inadequately assessed (Dorny et al., 2004). The choice of the diagnostic method can also be influenced by the availability and feasibility of use of the tests due to cost or technical capacity(Lightowlers et al., 2016).

2.5.1 Diagnosis of *Taenia solium* taeniasis

Little information exist on the prevalence of taeniasis because some of the available methods lack sensitivity and specificity or both and most studies have reported a prevalence of between 1 to 2% (Mahanty & Garcia, 2010).

Examination of faeces samples for *Taenia* eggs using microscopy

Identification of *Taenia* eggs through microscopic examination of faecal samples has been used by several epidemiological studies and to monitor intervention on control of taeniasis Li et al. (2013) in China, Jeon et al. (2013) in Lao PDR, and Watts et al. (2014) in Peru. The method has low sensitivity as was demonstrated by Li et al. (2013) and Hall et al. (1981). Coprological examination may be useful in identifying the presence of *Taenia* tapeworm but the method will not determine the species of *Taenia* present as the eggs are indistinguishable (Lightowlers et al., 2016). Identification of the eggs at species level is possible but will depend on the goal of diagnosis, whether for purposes of treating positive cases or for monitoring control interventions (Lightowlers et al., 2016).

Coproantigen detection or copro-ELISA can be used to detect antibodies in parasite products passed together with proglottids in faeces and have high specificity and sensitivity (Allan et al., 1990; Guezala et al., 2009). The test relies on polyclonal antisera which present the challenge of different batches of polyclonal antisera having different titres and spectrum of antigen specificities making replication of the method difficult (Lightowlers et al., 2016). All the methods rely on specialized reagents and are currently not available commercially and this has limited their use in epidemiological studies(Lightowlers et al., 2016).

Specific antibody detection in serum

Taenia spp. tapeworms induce specific antibodies that can be detected in serum and the antigens have been found to be useful for serological diagnosis (Heath et al., 1985; Jenkins & Rickard, 1985; Wilkins et al., 1999). Levine et al. (2004, 2007) developed a serological test for taeniasis which can be useful in *T. solium* control programs, however, antibodies may remain detectable even after treatment and this remains an area of concern(Lightowlers et al., 2016).

DNA-based methods

Several methods which can identify *Taenia* species specific DNA using PCR technology have been developed, however few are available for detection of *T.solium* DNA (Mayta et al., 2008; Nkouawa et al., 2010; Praet et al., 2013). PCR-based methods which can detect *T.solium* specific proglottids are advantageous and the detection of taeniasis using only a fecal sample is valuable

(Lightowlers et al., 2016). Multiplex PCR for diagnosis of taeniasis as developed by Yamasaki et al. (2004) is useful particularly in areas where there is co-occurrence of different species of *Taenia* (Lightowlers et al., 2016). Several challenges exist which hinder the use of copro-PCR in monitoring of interventions including the technical know-how required, high costs and the difficulties in extraction of DNA from faeces. The loop-mediated isothermal amplification (LAMP) developed by Nkouawa et al. (2010) addressed some of these challenges (Lightowlers et al., 2016).

2.5.5 Diagnosis of porcine cysticercosis (PCC)

Monitoring porcine cysticercosis has been in most cases used to monitor *T. solium* control activities and in epidemiological studies due to the less expertise and ethical considerations required in pigs. Pigs also have a shorter life span providing a time sensitive measure of infection status(Lightowlers et al., 2016). The reduction in porcine cysticercosis prevalence and incidences may be expected to translate to reduced human *T. solium* taeniasis cases and consequently reduction in the burden of human cysticercosis (Lightowlers et al., 2016). Cysticercosis can be detected in live pigs by tongue examination and serological testing as well as inspection of carcasses at slaughter (Willingham & Engels, 2006). The enzyme- linked-immunosorbent assay (ELISA) for antigen or the immunoblot test for antibody detection are the most commonly used serological methods in epidemiological studies in Africa (Dorny et al., 2004). The prevalence figures are affected by the sensitivity and the specificity of the diagnostic tests (Dorny et al., 2004; Lightowlers et al., 2016). To be able to monitor the success of *T. solium* control interventions from baseline to endline, good diagnostics are required. However, the diagnostics techniques are not readily available in sub-Saharan Africa, and this may have led to under-reporting or over-reporting of the infections.

Lingual examination and meat inspection

Lingual Examination entails visual inspection and palpation for cysts on the ventral surface of the tongue and is used by farmers and pig traders in endemic countries. It is an inexpensive and quick way of identifying pigs infected with PCC but has low sensitivity as low as 16.1% (Dermauw et al., 2016). The technique can attain 100%specificity if conducted by someone with experience (Dorny et al., 2004; Gonzalez et al., 1990). However, the sensitivity of the technique depends highly on the intensity of infection of the animals and can be high in pigs with high number of cysts and less in pigs with low number of cysts (Dorny et al., 2004; Gonzalez et al., 1990; Sciutto et al., 1998). This method of detection therefore, generally underestimates the prevalence of PCC(Willingham & Engels, 2006).

Different countries have varying official guidelines and practices for the detection of PCC at slaughter (Lightowlers et al., 2016; Willingham & Engels, 2006). In some countries only visual inspection is carried out on one or several selected muscle and organ sites, while in other incisions in some of these muscle groups may be required. In South Africa Sithole et al. (2019), concluded that the meat inspection procedures used were not sensitive enough to detect cases of porcine cysticercosis in slaughter places. Additionally, some of the sites like the back and hind leg which have high cysts counts were not normally part of meat inspection protocols(Sithole et al., 2019).

In Wambizzi abattoir in Uganda, one of the biggest pig abattoirs in Uganda, meat inspection was observed to be not a very sensitive method because slaughtering starts early before the meat inspectors arrive (no inspection) and in the early hours inspections is done using torches which may not provide adequate lighting (Roesel et al., 2016). During the inspection hypaxial muscles and sternal intercostal muscles including a portion of the rectus abdominis muscle are inspected for *T. solium* cysts. If cysts are found the masseter and thigh muscles are inspected (Roesel et al., 2016). This method of selective inspection can be insensitive especially if the pig has low cyst burden (Phiri et al., 2006). Condemnation of carcasses is reported to the management of the abattoir and city council and paraffin is poured on the carcasses and they are buried around the premises (Roesel et al., 2016).

Use of serological tests

Immunodiagnostics in pigs provides a detection method for use in live pigs more sensitive than lingual examination and is used in prevalence and community-based surveys as well as intervention studies(Willingham & Engels, 2006). The techniques developed for the diagnosis of cysticercosis in humans have also been adapted for use in detecting *T. solium* infection in pigs, including both antibody (enzyme linked immune electro transfer blot (EITB), Antibody-ELISA and antigen detection (Ag-ELISA)(Ito et al., 2003; Murrell et al., 2005).

Antigen-ELISA is the most appropriate immunodiagnostic test for detecting porcine cysticercosis (Lightowlers et al., 2016; Willingham & Engels, 2006) but the test does not allow differentiation of larval *T. solium* infections from larval infections of other *Taenia* species such as *T. hydatigena*(Cortez et al., 2018; Dorny et al., 2004). Most recent studies conducted in Uganda and elsewhere have used HP10 Ag-ELISA(Harrison et al., 1989, 2005)and the commercially available ApDia Ag-ELISA(ApDia, 2019; Dorny et al., 2004) to test for prevalence of porcine cysticercosis (Kungu et al., 2017; Nsadha et al., 2014; Thomas et al., 2016). The sensitivity and specificity of these method has been estimated to be 94.7% and 86.7% , respectively (Dorny et al., 2004).

Although, immunological diagnostics have superior benefits in terms of sensitivity and specificity, the consideration of the context where sample handling and analysis will occur may influence their use due to the requirement for refrigeration, centrifuges and access to electricity as well as technical expertise (Lightowlers et al., 2016).

2.5.8 Diagnosis of Neurocysticercosis (NCC)

Neurocysticercosis can be diagnosed using neuroimaging such as Computed Tomography (CT)and magnetic resonance imaging (MRI) and serological techniques in clinical settings (Garcia et al., 2012; Thomas, 2015)**.** Development of serological tests like the Enzyme-linked Immunoelectrophoresis Blot (EITB) and Western blot which are highly sensitive solved the challenge of limited resources in conducting neuroimaging on population basis in endemic settings (Lightowlers et al., 2016; Tsang et al., 1989).

The infections of humans by *T. solium* cysticercosis can remain for many years if not treated and therefore, the prevalence of human cysticercosis will not be a good measure of interventions outcomes unless the interventions are long term (Lightowlers et al., 2016). Due to these challenges the monitoring of interventions aimed at reducing the burden of human cysticercosis measure the intervention outcomes in porcine populations (Lightowlers et al., 2016).

2.6 Control and prevention *T. solium* taeniasis/ cysticercosis

T. solium is unique among the zoonoses in that it is maintained in nature with human as the only definitive host (WHO, 2014b). The life cycle is entirely dependent on the transmission between humans and pigs and therefore, breaking the transmission paths can lead to total elimination of the worms(Gemmell et al., 1983)as simplified in Figure 3 (de Coster et al., 2018). Interventions to break the transmission cycle can be grouped into mass human antiparasitic therapy or treatment of individuals patients (interruption of the sexual reproduction of the adult worm), antiparasitic treatment ofpigs alone or combined with vaccination of pigs, improved meat inspection, human health education on proper personal and household hygiene, proper cooking of pork and good pig husbandry (de Coster et al., 2018; Gabriël et al., 2017; Garcia et al., 2016)(Figure 3). Different combinations of these control strategies have been tested in different endemic setting resulting to varying levels of impact but only one has since been tested in Uganda(Nsadha et al., 2021).

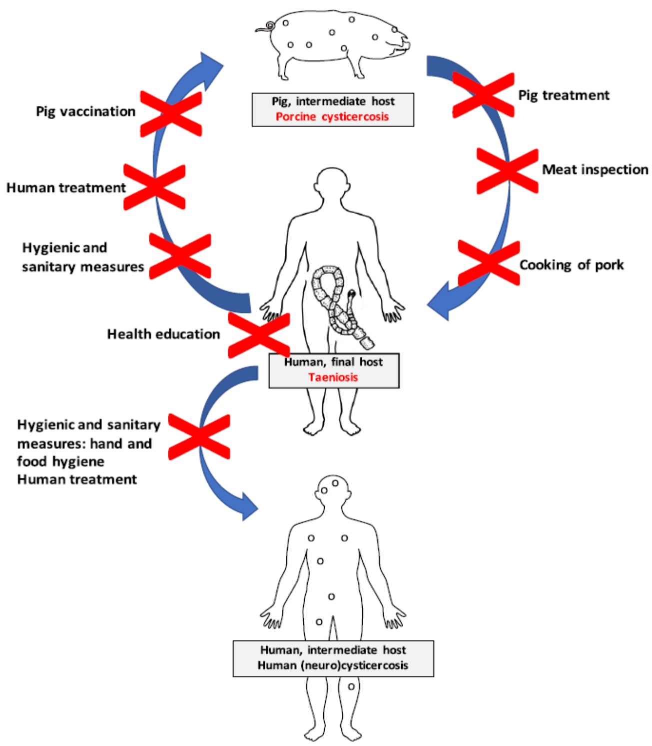

Figure 2. 3: Potential points (X) along the *T. solium* life cycle where transmission can be disrupted: (de Coster et al., 2018).* permission was sought and granted from the original authors.

2.6.1 Human treatment

Thomas (2015) conducted a landscape analysis study which concluded that mass drug administration (MDA) with niclosamide or praziquantel can reduce transmission in the short run. However, mathematical models conducted recently have suggested that a single round may not be sufficient due to reinfection(Braae et al., 2016; Winskill et al., 2017). Consequently, recent MDA programs have included several treatment rounds using praziquantel(Braae et al., 2017) and using albendazole(Ash et al., 2017).

A study in Peru Garcia et al. (2016), implemented six different strategies and demonstrated that it was possible to interrupt *T. solium* transmission over a large geographical area, thereby preventing PCC and NCC. The study was implemented throughscreening of humans and pigs, antiparasitic treatment, prevention education, and pig replacement in three phases over a period of three years with the final phase combining mass vaccination of the pigs with TSOL18 vaccine and treatment of humans with niclosamide (Garcia et al., 2016).

2.6.2 Health education

Health education as a stand-alone may not be enough to control *T. solium*(Thomas, 2015), but well-designed health education strategies targeting change of behaviour, attitudes and practices have been shown to reduce the prevalence of *T. solium* infections (Ngowi et al., 2008; Sarti & Rajshekhar, 2003). Recent health education interventions have been tried in Burkina Faso (Carabin et al., 2018) which showed decrease in cumulative incidence (ratio = 0.65) and decrease in prevalence proportion ratio 0.84. In Zambia, Hobbs showed that health education improved knowledge score among school students.

In Tanzania, Ertel et al. (2017) tested the use of the computer-based *T.solium* health education tool, *The vicious worm(https://theviciousworm.be/),*among 79 professional and showed knowledge improved two weeks after intervention. Separately, Mwidunda et al. (2015) also showed increased knowledge among school children in Tanzania after health education intervention. The PRECED-PROCEED model was used in Tanzania to present educational messages and showed a 43% drop in PCC incidence as well as increase in disease knowledge and drop in consumption of infected pork (Ngowi et al., 2009).

2.6.3 Pig level interventions

Interventions targeting pigs have also been tried and include pig vaccination (to prevent the development of larval metacestodes) and pig treatment (to eliminate already existing larval metacestodes).Preventing pigs from accessing infective human stool by confinement can be the most straightforward to control PCC but a number of barriers exist on confinement (de Coster et al., 2018). Although farmers may perceive the health risks of free-range pigs, socio-economic reasons may make them not adopt confinement as was observed in Zambia (Thys et al., 2015). The barriers to pig confinement and the drivers for such behaviour has not been studied in Uganda. The TSOL18 vaccine has been shown to be effective in killing *T.solium* before developing infectious cysts (metacestodes) but the addition of susceptible new born pigs into the pig herd remains a challenge (Huerta et al., 2001).

The vaccination of pigs with TSOL18 and administration oxfendazole (OXF) to eliminate active infections (which existed before vaccine administration) has been proposed as the solution to the stated problem (de Coster et al., 2018). This strategy requires a booster vaccination and treatment and has been shown to be effective in a study in Cameroon (Assana et al., 2010) and was recently tested and found effective in Uganda (Nsadha et al., 2021). A recent market scoping study for the TSOL18 vaccine in Uganda showed 19% of 294 farmers in total were willing to pay USD 2.61 for the vaccine per pig with the current combination of two doses plus treatment with OXF (Dione et al., 2021).

2.6.4 Sanitation

Improving sanitation and hygiene through health education has been shown to be effective against diseases transmitted through human waste(Fleury et al., 2013). Community-based programs like the community led total sanitation (CLTS) aimed at achieving free open defecation villages failed in Zambia due to sociocultural characteristics of the community which are hard to change and were poorly understood (Bulaya et al., 2015;Thys et al., 2015). The feasibility and acceptability of the control strategies against *T. solium* by local stakeholders in Uganda has not been evaluated.

2.6.5 Integrated control strategies

Targeting both the human and porcine hosts to tackle *T. solium* infections presents greater opportunities for control of the parasite (Thomas, 2015). Mathematical models have also shown that to achieve rapid and sustained impact on disease transmission, both treatment of pigs and humans is required (Braae et al., 2016; Winskill et al., 2017). Combined efforts would be ideal, but are more complex and expensive to implement (Lightowlers & Donadeu, 2017). Several combined strategies to combat *T. solium* have been tried. For example, combining health education with the detection and treatment of *Taenia spp.* carriers or mass drug administration to the community and the combination of vaccination and anthelmintic treatment of pigs (Thomas, 2015;Assanaet al., 2010;Pawlowski et al., 2005).

The integration of *T. solium* control efforts into the existing national disease control programmes like national school deworming programmes can create support for *T.solium* control among government agencies (Braae et al., 2016). National school deworming programs targeting schistosomiasis use praziquantel which has also been identified as the drug of choice to treat taeniasis by World Health Organization (WHO, 2021b). School based MDA with praziquantel was shown to reduce the prevalence of *T. solium* infections in Tanzania(Braae al., 2016).

The treatment of pigs for PCC and other gastrointestinal parasite provides another opportunity for integration. The administration of single dose oxfendazole at 30mg/kg to pig has been shown to be effective against *T. solium* cysts in pigs (Kabululu et al., 2020; Mkupasi et al., 2013; Nsadha et al., 2021) and other pig nematodes like *Ascaris suum, Oesophagostomum* spp.*, Trichuris suis* and

Metastrongylus spp.in pigs(Alvarez et al., 2013; Mkupasi et al., 2013).The evidence in terms of co-infections status of pigs with both PCC and gastrointestinal parasites to support integrated control in Uganda has not been established.

2.6 Context and enabling environment for control of *Taenia solium* infections

Disease control interventions are implemented in local environments which are complex and in many instances with various stakeholders having different opinions and roles(Connell et al., 1998). These aspects, and more encompass the context and can be defined as the features of the circumstances and set of characteristics for which an intervention is conceived and developed and in which it is implemented and evaluated (Craig et al., 2018; Pfadenhauer et al., 1993). Context interacts, influences, modifies and facilitates or constrains the implementation of an intervention (Pfadenhauer et al., 1993). Conceptualization of the context and the decision on which aspects of context to be addressed in an intervention can be challenging and should be taken as a major research aspect(Craig et al., 2018). Several frameworks exist to guide the consideration of context mostly in health intervention promotion (mostly in a health care system) but most of them are also relevant for NZD interventions.

Damschroder et al. (2009) described the consolidated framework for implementation research which comprise of five domains - the intervention, inner and outer setting, the stakeholders involved, and the process of implementation which interact to influence success of the implementation. Poland et al. (2009) developed an analytic framework to guide intervention design and implementation which has 20 questions to help identify the features of context and are organized into five categories. These include; Diversity across and within components of a setting, received knowledge, local determinants of health, stakeholders and their interests and finally power, influence and social change (Poland et al., 2009).

Pfadenhauer et al. (1993)developed the Context and Implementation of Complex Interventions (CICI) framework for use in health technology assessment. The framework identified eight domains forming context: Setting, geographical, epidemiological, socio-cultural, socio-economic, ethical, legal and political; five domains on implementation: Provider, organization and structure, funding and policy (Pfadenhauer et al., 1993). Craig et al. (2018) described context as comprising of baseline epidemiological information, socio-economic and cultural characteristics, geographical and environmental features, ethical considerations, policy and legal feature, financial, political, and historical factors. Closely linked to this is the supportive legal and policy frameworks including their implementation and enforcement, institutional structures including roles and responsibilities, participation and capacity building of stakeholders and other actors (EU, 2015; USAID, 2011).

For neglected tropical diseases including *T. solium*, limited frameworks exist to guide the design, implementation and evaluation of the different control interventions while in consideration of the features of context. Bardosh (2018), proposed a socio-anthropological framework and critically discussed its key domains by assessing three case studies involving the scale up of interventions against rabies in Tanzania, trypanosomiasis in Uganda and achievement of total sanitation in Zambia. The framework consist of five domains which include; the terrain of intervention (including seasonality and geographical variability); community agency (including local knowledge, risk perceptions, behaviors, leadership and social pressure); the strategies and incentives of field staff (skills, motivations, capabilities and support); the socio-materiality of technology (characteristics of intervention tools and the adoption process itself); and the governance of interventions (policy narratives, available expertise, bureaucracy, politics and the utilization of knowledge) (Bardosh, 2018). Braae et al. (2019) put forward the only current guide specifically for *T. solium* interventions, a stepwise approach to guide the design and implementation of interventions against *T. solium* as summarized in box 1. The framework does not explicitly address context, but the steps proposed can lead to fulfilment of contextual considerations.

Box 2. 1: The stepwise approach to the control and elimination of *Taenia solium* (Braae et al., 2019).

Step 1 and 2: Initial disease distribution and burden needs to be estimated and the presence and awareness of the parasite recognized.
Step 3: Secure political commitment, stakeholder engagement, both necessary for programme funding.
Step 4: Establishment of a 'cross ministerial One Health coordinating unit' responsible for coordinating and gathering information relating to *T. solium* control initiatives through the political commitment secured earlier.
Step 5: The one health unit should lead the development regional or national success goals for control, targets for success and identify timelines for these, based on the international tripartite agreement.
Step 6: Identify the country specific control algorithm from the internationally agreed 'intervention tool kit', authorize local institutions to undertake the programme.
Step 7: Build capacity by training staff, ensure availability of intervention tools such as delivery of drugs and vaccines, and support local institutions to strengthen involvement of the local communities.

The relationship between context and the interventions will influence the success or failure and understanding these relationships will help perceive how impact will be achieved and why impacts vary from one context to the other (Craig et al., 2018). Enabling environment include institutional structures including roles and responsibilities, participation and capacity building of stakeholders and other actors and the presence of supportive legal and policy frameworks including their implementation and enforcement (EU, 2015; USAID, 2011).

No framework exists currently to specifically identify the contextual features relevant specifically to implementation of *T. solium* interventions. The evaluation of how these features have been considered in selected studies is lacking. It is imperative that the contextual factors relevant to the control of *T. solium* infections in the various endemic settings and the influence they have on implementation are identified as well as the interactions which exist between the contextual factors and the intervention. The socioeconomic and cultural characteristics of local stakeholders which may influence the success of the interventions has also not been evaluated in Uganda.

2.8 RESEARCH GAPS

Failure of the interventions to achieve expected impact could be attributed to failures in addressing the various contextual factors or creating an enabling environment needed to underpin success. The following research gap exists: -

1. There is information gap on the type of contextual factors that might have influenced the success or failure of control interventions tested in different endemic areas of the world.
2. Specifically, for Uganda, the socioeconomic and cultural characteristics of local stakeholders which may influence the success of the interventions has not been evaluated.
3. The evidence in terms of co-infections status of pigs with both PCC and gastrointestinal parasites to support integrated control in Uganda is lacking.
4. The feasibility and acceptability of the control strategies against *T. solium* by local stakeholders in Uganda has also not been evaluated.

CHAPTER THREE

A QUALITATIVE ASSESSMENT OF THE CONTEXT AND ENABLING ENVIRONMENT FOR THE CONTROL OF *TAENIA SOLIUM* INFECTIONS IN ENDEMIC SETTINGS

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ABSTRACT

Taenia solium (*T. solium*), is a zoonotic helminth causing three diseases namely, taeniasis (in humans), neurocysticercosis (NCC, in humans) and porcine cysticercosis (PCC, in pigs) and is one of the major food-borne diseases by burden. The success or failure of control options against this parasite in terms of reduced prevalence or incidence of the diseases may be attributed to the contextual factors that underpin the design, implementation, and evaluation of control programmes.

The study used a mixed method approach combining systematic literature review (SLR) and key informant interviews (KII). The SLR focused on studies that implemented *T. solium* control programmes and was used to identify the contextual factors and enabling environment relevant to successful inception, planning, and implementation of the interventions. The SLR used a protocol pre-registered at the International prospective register of systematic reviews (PROSPERO) number CRD42019138107 and followed PRISMA guidelines on reporting of SLR. To further highlight the importance and interlinkage of these contextual factors, KII were conducted with researchers/implementers of the studies included in the SLR. The SLR identified 41 publications that had considerations of the contextual factors. They were grouped into efficacy (10),

effectiveness (28) and scale up or implementation (3) research studies. From the SLR and KIIs, the authors identified contextual factors including epidemiological, socioeconomic, cultural, geographical and environmental, service and organizational, historical and financial factors. The enabling environment was mainly defined by policy and strategies supporting *T. solium* control. Failure to consider the contextual factors operating in target study sites was shown to later present challenges in project implementation and evaluation that negatively affected expected outcomes. This study highlights the importance of fully considering the various domains of the context and integrating these explicitly into the plan for implementation and evaluation of control programmes. Explicit reporting of these aspects in the resultant publication is also important to guide future work. The contextual factors highlighted in this study may be useful to guide future research and scale up of disease control programmes and demonstrates the importance of close multi-sectoral collaboration in a One Health approach.

3.1 Introduction

The zoonotic parasite *Taenia solium* (*T. solium*) and its associated diseases; taeniasis, porcine cysticercosis (PCC) and human neurocysticercosis (NCC), are diseases of great public health and economic significance (Carabin et al., 2011; Del Brutto & García, 2015; García et al., 2003).The parasite's disease complex is among the neglected tropical diseases (NTDs) - diseases often associated with resource-constrained, marginalized and vulnerable populations, where poor animal husbandry may be practiced, and where there is limited access to clean water and sanitation (Sarti et al., 1992; Utzinger et al., 2010). The 2012 'roadmap', endorsed by the World Health Assembly in 2013, called for action to prevent, control, eliminate or eradicate NTDs including *T. solium* cysticercosis by 2020. The 2020 milestones of "Interventions scaled up in selected countries for *T. solium* taeniasis/cysticercosis control and elimination" have not been met. The updated 2021-

2030 roadmap now provides specific targets for a number of countries with "intensified control in hyperendemic areas" (World Health Organization, 2019).

Several control options focusing on human treatment, pig vaccination and treatment, health education, and/or sanitation exist for the control and eventual elimination of *T. solium* infections. Combinations of any of the listed options have been tested with varying degrees of success(de Coster et al., 2018; Thomas, 2015). As each component of the 'toolkit' of control options has either been demonstrated to be effective under experimental conditions or has a strong biological plausibility, we hypothesize that the success or failure of the interventions as measured by significant reduction in human or porcine prevalence/incidence of disease, may be attributed to the interaction between the intervention and factors present in the context within which they were planned, implemented, and evaluated.

Context can be defined as the features of the circumstances for which an intervention is conceived and developed, implemented and evaluated(Craig et al., 2018). Context includes baseline epidemiological information, socio-economic and cultural characteristics, geographical and environmental features, ethical considerations, policy and legal features, financial, political, and historical factors. On the other hand, the enabling environment encompasses institutional structures including roles and responsibilities, participation and capacity building of stakeholders and other actors and the presence of supportive legal and policy frameworks including their implementation and enforcement(EU, 2015; USAID, 2011). These factors can affect the delivery and evaluation of interventions contributing to the achievement or failure to achieve, the expected impact. Consideration of the context early enough during programme inception and planning will create space for recognition of inherent challenges and devising of ways of adapting to forestall project failures.

It is widely accepted that the control and eventual elimination of *T. solium* infections will require a One Health approach. This approach is strongly advocated for by many including the FAO/WHO/OIE tripartite guide(WHO, 2014a, 2019). The Tripartite Guide to Addressing Zoonoses in Countries provides a practical manual to guide the "prevention, preparedness, detection and response to zoonotic threats at the animal-human-environment interface" using multi-sectoral principles(WHO, 2019). One Health approaches are inherently trans-disciplinary, integrating knowledge both from different science disciplines and stakeholder communities to facilitate collaboration(Hitziger et al., 2018; OECD, 2020)with a strong focus on the environmental, ecological, social and economic factors in the control and mitigation of human and animal health challenges (Häsler et al., 2012).

Several frameworks exist to guide the design, implementation, and evaluation of control strategies against zoonoses in consideration of One Health principles. Rüegg et al. (2017) put forward a comprehensive blue print on evaluation of the 'One Health-ness' of such projects and programs, this framework has since been used by Paternoster to evaluate the degree of One Health implementation in the integrated surveillance of West Nile virus in Italy. Bardosh, (2018)proposed a socio-anthropological framework and critically discussed its key domains by assessing three case studies involving the scale up of interventions against rabies in Tanzania, trypanosomiasis in Uganda, and achievement of total sanitation in Zambia. Braae et al. (2019) put forward the only current guide specifically for *T. solium* interventions, that is a step wise approach to guide the design and implementation of interventions against *T. solium*.

To the best of our knowledge this is the first study to critically evaluate how the contextual factors have been considered within *T. solium* control programmes. The present study considers hitherto understudied aspects of the context and the enabling environment that may have contributed to the success or failure in the implementation of *T. solium* control interventions. We identify and discuss the important factors to consider and the potential challenges which might arise if the context is not factored in project planning, implementation and evaluation illustrated by examples in the published literature and the personal experience of researchers involved in such programmes. The description and explicit reporting of these contextual factors can assist in the design, implementation, and evaluation of *T. solium* control programmes.

3.2 Materials and methods

3.2.1 Study design and data collection

The research questions

The overall research question was: "What aspects of the context appear to support the success of *T. solium* interventions?" Specific questions included: (i) what contextual factors influenced the design and planning of the intervention? (ii) what aspects of context influenced the implementation and evaluation of the interventions? and (iii) what steps did the projects take to address the different contextual factors and with what results?

3.2.2 Sources of data

3.2.3 Systematic literature review

A systematic literature review on field-based interventions against *T. solium* published between January 1950 and May 2019 was conducted to identify what aspects, if any, of the context and enabling environment were reported in the literature. Studies from any country published in English were eligible for inclusion. The SLR was conducted following the PRISMA guidelines for conducting and reporting systematic reviews. The PRISMA flow chart is shown in Figure 3.1 and the PRISMA reporting checklist can be found in appendix 2. A protocol was pre-registered at the International prospective register of systematic reviews (PROSPERO) number CRD42019138107.

Search methods, inclusion, and exclusion criteria

The search was conducted in the following electronic databases: PubMed, CAB direct, World of Science, African Journals Online (AJOL), IngentaConnect, Google Scholar and LILACS (This contains most important and comprehensive index of scientific and technical literature of South America and the Caribbean). The Boolean operators “AND” and “OR” were used to combine the relevant search terms depending on the specification of the electronic database. For example, the search algorithm used in PubMed was as follows;- ("*Taenia solium*" OR "*T. solium*" OR Cysticerc* OR *Taeni**) AND (control OR elimination OR eradication OR integrated OR Random OR “Clinical trials” OR Challenge OR efficacy OR Praziquantel OR niclosamide OR albendazole OR "mass drug administration" OR "TSOL18" OR vaccination OR oxfendazole OR education OR latrines OR sanitation OR husbandry OR "pig housing" OR confinement OR "meat inspection" OR "hand washing" OR integration OR Biosecurity OR “community sanitation” OR “community hygiene programs”). The search terms were adapted to the other online databases depending on their specifications.

The following exclusion criteria were used: studies not relating to humans or pigs, studies not relating to Neglected Tropical Diseases (NTDs); studies on aspects of NTDs which do not discuss issues relevant to *T. solium* control; studies on epilepsy NOT related to NCC; studies on other parasites except soil transmitted helminths; papers relating to clinical symptoms; experimental studies not community-based; diagnoses and treatment of NCC including case studies; purely epidemiological studies on *T. solium,* papers on diagnoses of *T. solium* cysticercosis/taeniosis (including diagnostic imaging) and papers on aspects of basic sciences (immunology/molecular biology/physiology). For articles published in a language other than English, the abstracts were screened first and if they met the inclusion criteria, the English version of the full article was searched and if not found the articles was excluded. Additional articles were identified by going through the list of bibliographies in selected articles. The risk of bias of individual studies was assessed subjectively by the first author by marking the studies as either low, medium, and high risk of bias based on availability of a description of sound methodology with regard to selection of subjects, data analysis and clear and complete reporting of the results.

The key elements of the review question are as simplified by the PICOT acronym below.

- Population: humans or pigs
- Intervention: Drugs for prevention and treatment (Praziquantel, niclosamide, albendazole; mass drug administration of either albendazole or praziquantel or both, TSOL18, vaccination, oxfendazole), education on use of latrines, sanitation, hand washing, pig husbandry, pig housing biosecurity; meat inspection, and "integrated community sanitation" or "community hygiene programs"
- Control: Non-treated, local/experimental study population or none
- Outcome: Efficacy, side effects, acceptance, costs, risk factors, change in knowledge, attitude and practices, prevalence, features of study area at implementation, Conceptual framework/impact pathway, stakeholders involved, challenges encountered.
- Time frame: Time limits – manuscripts published between Jan 1950 and May 2019.

Data from the manuscripts were extracted by the lead author into a Microsoft Excel spreadsheet developed and discussed with the other authors. Data was extracted on the type of the intervention implemented, country of intervention, the indicators monitored, and changes identified attributable to the intervention. Further aspects of the context were extracted, guided by the analytical framework outlined below (Table 3.1).

3.2.4 Key informant interviews

Key informant interviews were then conducted with key researchers from the studies identified through the SLR to further discuss their experience on how context and enabling environment influenced intervention design, implementation, and outcomes for *T. solium* control.

A key informant interview discussion guide was developed by the lead author and discussed among the co-authors. The KII discussion guide focused on the planning phase of the intervention, the type and roles of stakeholders involved, the supporting policy environment and context in which the interventions were implemented, how the implementation phase was carried out, a description of the evaluation stage and finally an outline of any challenges encountered.

Key informants invited for interview were either the principal investigator or a supporting researcher. Six respondents were female and five were male working in various capacities in different institutions across the world at the time of interview. Further demographic details on the key informants have been deliberately excluded from this publication to protect the anonymity of the participants since they could be identified by their peers in the field. All interviews were conducted in English and transcribed verbatim.

3.2.5 Analytical framework

The current study, builds from the socio-anthropological framework for NTD control(Bardosh, 2018), the step-wise approach for control of *T. solium*(Braae et al., 2019) and from other literature(Craig et al., 2018; EU, 2015; Harding & Oetzel, 2019; USAID, 2011). Craig et al. (2018) described the contextual factors to consider in population health intervention research which was adapted to highlight and discuss aspects relevant to *T. solium* interventions. The contextual factors and their relationship with the interventions are described in Table 3.1 and were used to guide a mixed inductive and deductive thematic analysis facilitated by NVivo software version 12 (QSR International Pty Ltd, 2010). The coding involved the identification of themes sitting within the adapted framework by Craig et al. (2018) through close line by line coding after thorough examination of the KII transcripts (Braun & Clarke, 2006). New themes were identified and discussed with the co-authors before inclusion into the coding frame. New themes were identified until data saturation appeared to be reached due to no new themes emerging. Data extracts (in italics) are included in this article and are identified with the data source (Key informant ID).

Table 3. 1:A synthesis of the contextual factors for Taenia solium control interventions adapted from Craig et al., (2018)

Contextual factor	**Description**	**Examples and applications to the case of *Taenia solium* interventions**
Epidemiological factors	Baseline incidence, prevalence, and distribution of the health problem of interest and its determinants in the target population	Baseline prevalence and incidence of PCC, taeniasis and NCC as driven by the underlying biological and socio-economic risk factors, the measure of the outcomes and its reliability, diagnostics methods used.
Socioeconomic factors	Distribution of social and economic resources among communities or populations affected by the intervention, water health and sanitation coverage and education levels	The motivation for rearing pigs, whether farming is subsistence or for income generation; current husbandry practices, including who makes decisions about how pigs should be reared and who provides the labour for pig rearing; level of knowledge and willingness/ability to change practices, including adopting the intervention technologies, income distribution among farmers, access to land or other resources, language, ethnicity, etc. that could affect

		interventions, other economic activities within the target area
Cultural factors	Beliefs, attitudes and practices among farmers, policymakers, practitioners, and those targeted by the intervention, cultural factors relating to pork consumption.	Beliefs, attitudes and practices surrounding pig rearing (e.g. pigs are supposed to be "natural cleaners/sanitation policemen" by eating human faeces), pork consumption (e.g. eating raw pork), and *Taenia solium* infection particularly NCC, (cultural norms and taboos around use of toilet), Local taboos/stigma on open defecation, knowledge of the disease and its impacts on their health and livelihood
Geographical and environmental factors	Features of the immediate or more distal (e.g. regional or national) physical environment, either natural or built.	Physical environment including natural and built environment, seasonal variation, access roads, target community location in relation to physical features like mountains, presence of rivers and ponds/lakes– potential for human effluent to contaminate and source of surface drinking water, use of river water for irrigation
Service and organizational	Characteristics, such as readiness to change and motivation, of the individuals delivering the intervention, the organizations in which they work and the wider service environment in which those organizations operate. Co-interventions that target the same risk	Ministry of health and Ministry of livestock, local provincial administration, One Health units, local and international non-governmental organizations (NGOs), willingness of ministries of health and livestock to support interventions, capacity and motivation of local government staff involved in project activities, willingness of local institutions including universities and NGOs to collaborate in the control of *T. solium*, competition for time allocation between

	factors, behaviouror outcomes within the same population as the intervention of interest	ministry and project activities. Existence of national deworming programs in the community or schools.
Ethical considerations	The extent to which implementers and recipients understand and agree about the benefits and harms of the intervention and can provide informed consent of exposure to the intervention and participation in associated research	Target population's common understanding about the benefits and harms from the intervention, capacity to make informed decision and give consent to participate, community empowerment to give consent on their own behalf and on behalf of their dependents especially for therapeutic interventions.
Policy, strategies and legal guidelines	The wider policy framework within which a specific intervention is embedded	*T. solium* control should be embedded in country's livestock disease control policies. Enforcement of some guidelines (for example meat inspection guidelines, local laws on pig husbandry)
Political	Distribution of power among stakeholders and others with an interest in promoting or obstructing the optimum design or implementation of the intervention	Power dynamics among stakeholders, structure of government. Political structures including influence and power of local administrators, interest of the local political leadership in the intervention
Historical	Continuing influence of past conditions, socio-political relationships, policies and legal frameworks	Influence of past involvement of target community in disease control interventions, positive or negative experiences with certain organizations
Financial	Sources and mechanisms of funding for the intervention and the wider payment, reward, incentive or charging structures in which they are embedded	Sources and mechanisms for funding for the intervention, costs versus the benefits, expected budget allocation by ministry of health and ministry of livestock, stability of funding during project implementation period.

3.2.6 Ethics statement

Ethical approval was obtained from International Livestock Research Institute's (ILRI) Institutional Research Ethics Committee (ILRI-IREC), reference number ILRI-IREC 2019-20. An informed consent form was sent as an attachment on the email inviting the key informants for the interview. Informed consent was obtained from the respondent by signing an electronic copy of the consent form or responding positively on the invitation for interview. Before the start of the interview session consent was sought for recording of the discussion.

3.3 Results and discussion

3.3.1 Systematic literature review descriptive results

The search identified 10,868 abstracts of which 41 were retained after removing duplicates and screening under various inclusion and exclusion criteria (Fig. 3.1: PRISMA flow chart). The studies included were from 3 different continents: Africa 15, Latin America 18, and Asia 8 studies (Fig. 3.2). Most studies reported results of control strategies targeting one of the three diseases: PCC (17) and taeniosis (8) or various combinations of the diseases (16). No study focused entirely on NCC prevalence or incidence in the short term. There was a high level of heterogeneity between the different studies and therefore it was not possible to carry out a meta-analysis to achieve a single estimate of the effect of the interventions. This is because the different studies used different outcome measures and diagnostic techniques. The identified studies also had paucity of information on the enabling environment and contextual features underpinning the design, implementation, and evaluation of the interventions. However, more information was collected through the key informant interviews. In total 33 studies were scored as being of medium quality and 8 studies of good quality based on subjective assessment by one author.

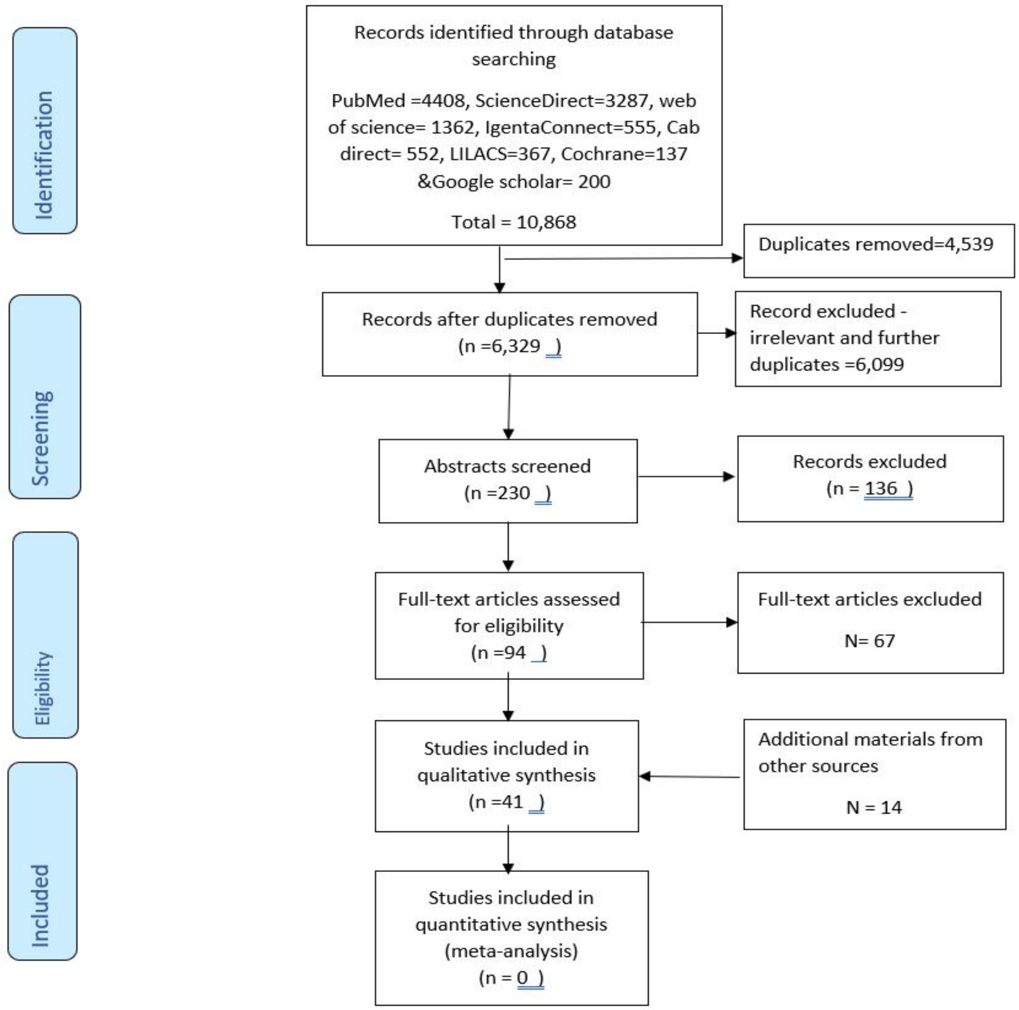

Figure 3. 1:PRISMA flow chart of the selection process in the systematic literature review of contextual factors for *T. solium* control

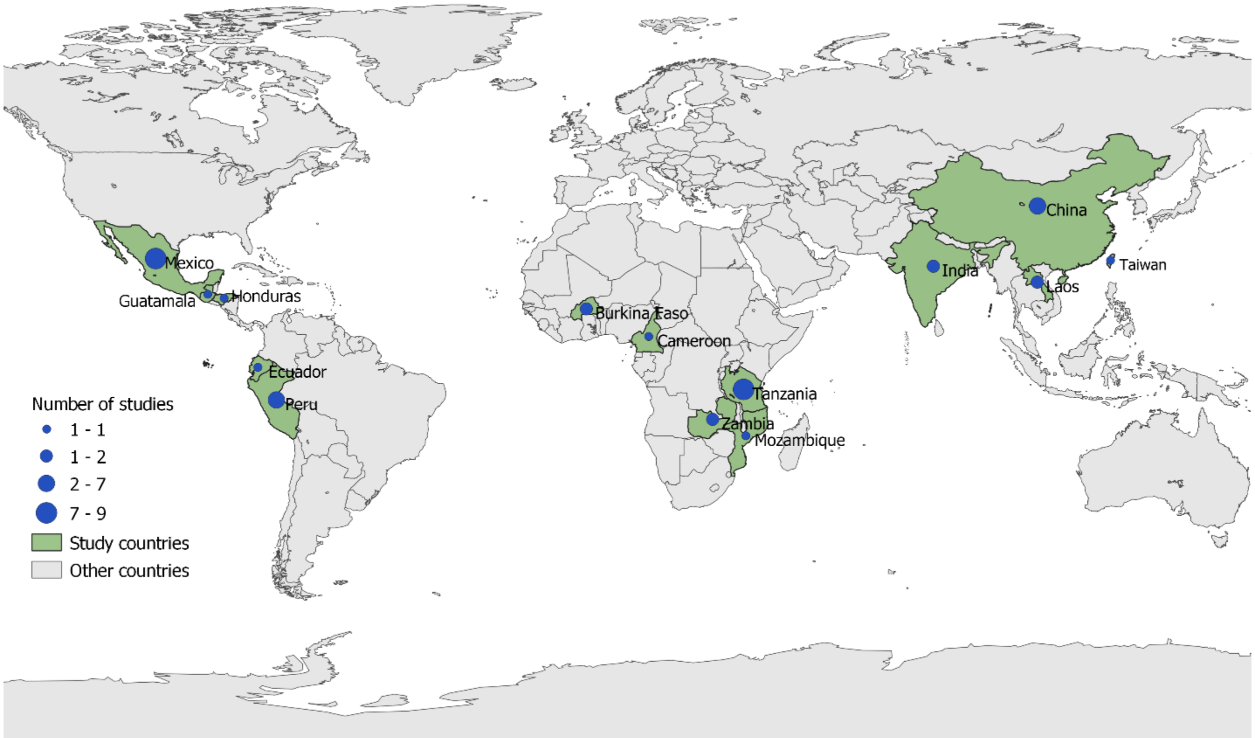

Figure 3. 2:World distribution of studies included in the SLR on contextual factors for *T. solium* control

Base map Link: https://gadm.org/download_world.html

3.3.2 Key Informants Identification

Of the forty-one journal articles identified for inclusion to the qualitative analysis, five listed the same corresponding authors as another article. Eleven out of the 36 articles had no listed email address for the corresponding author and a further 2 had email addresses which did not work, and no alternative emails could be found. In total 23 corresponding authors were identified for the interview, of which eleven authors agreed to be contacted for a key informant interview representing a 48% response rate.

3.3.3 Describing the contextual factors and enabling environment supporting control of *T. solium*

The manuscripts identified through the SLR had a paucity of data on the contextual factors identified through the modified Craig et al. (2018) framework. Contextual factors were however identified from the methodology and discussion sections which were further explored during the key informant interviews (S1 Table, S2 Table and S3 Table: Summary of the studies included in the SLR process in Appendix 1). The analysis of contextual factors presented here is organized according to the category of study. This was because the influence of context and enabling environment may vary depending on the study type and scale of implementation. The categories are those which focused on testing the efficacy of interventions under controlled conditions (10 studies), those which tested effectiveness of control intervention under "real-world" conditions (28 studies), and finally those which focused on implementation or scale-up of interventions (3 studies).

In the analysis we show how the different contextual factors were considered by the implementers of the projects reported in the primary studies and how the implementers adapted to changes in context during implementation.

3.3.4 Contextual factors in efficacy studies

Generally, efficacy studies are performed in an experimental setting or under ideal conditions where most of the parameters are controlled. Their design increases the chances of detecting effect if it exists but does not consider wider contextual factors that may influence an intervention's effect at scale. The studies identified were mostly field based with limited geographical coverage.

Ten studies focused on testing the efficacy of different drugs and education programmes. These included administration of albendazole in humans which showed limited success in treatment of taeniasis (Chung et al., 1991; de Kaminsky, 1991), oxfendazole in pigs (Garcia et al., 2001), vaccination against PCC using a variety of vaccine candidates(Huerta et al., 2001; Jayashi et al., 2012; Molinari et al., 1997; Morales et al., 2008; Sciutto et al., 2007) health education (Ertel et al., 2017a) and use of pumpkin seed (*Cucurbita moschata* Duch) and areca extract (*Areca catechu*) (Li et al., 2012). These studies aimed at proof of concept and most of those testing drugs were conducted in the late 1980s and early 1990s a time when efforts to identify a suitable cestodocidal drug for taeniosis were ongoing. Few contextual factors were considered in these studies and those that did were strongly associated with the logistics of trial delivery and interpretation. Four of the contextual factors were identified as being considered in efficacy studies and a summary of these can be found in Table 3.2.

Table 3. 2:Summary of contextual factors analysis for efficacy studies

Contextual factor	Specific examples from the studies	References and country of focus
Epidemiological factors	○ Challenges in evaluation including loss to follow-up ○ Reduction in samples sizes due to loss to follow up could have reduced the statistical power of the evaluations ○ Lack of cooperation from study participants.	(Chung et al., 1991; de Kaminsky, 1991) in Honduras and Taiwan respectively (de Kaminsky, 1991; Sciutto et al., 2007)both in Mexico
Social and economic factors	○ Commercially oriented farmers were more supportive of the control interventions in areas where pigs are an important source of income. ○ Farmers may not retain pigs recruited for study in absence of an alternative or incentive/compensation.	(Morales et al., 2008) in Mexico
Cultural factors	○ Importance of traditional medicine among the community supported uptake of the intervention ○ Gender roles affected the participation of women in training sessions.	(Ertel et al., 2017a; Li et al., 2012) in Tanzania and China respectively.
Service and organization factors	○ Extensive sensitization of the local community and involvement of various stakeholders could translate to smooth delivery of the intervention	(Jayashi et al., 2012) in Peru

Epidemiological factors

For de Kaminsky, (1991) and Chung et al. (1991) who tested the efficacy of albendazole in treating taeniasis in Honduras and Taiwan respectively, little is reported on the contextual environment they operated in and the challenges reported are mostly technological including the unreliability of the diagnostic techniques used. de Kaminsky, (1991) cited lack of cooperation from the study participants especially in stool sampling and recovery of strobila as the main challenge during evaluation, highlighting the need to fully engage communities in research to ensure the indicators selected may be accurately measured.

For all the studies targeting pigs for treatment or vaccination the major challenge cited was loss to follow up due to several reasons including sale of the pigs, slaughter of the pigs for home consumption or death of the pigs and reproduction state where pregnant sows were excluded. Reduction in sample size leads to a reduced statistical power to detect an effect, potentially impacting the overall findings of the study. Farmers in most cases rear pigs for subsistence and projects having longer follow up periods should consider providing incentives to farmers not to sell the pigs under study. In their study in Cuentepec Mexico Sciutto et al. (2007)(Sciutto et al., 2007)(Sciutto et al., 2007)reported a loss to follow-up of 215 pigs (56%) where the pigs were sold or were missing. Huerta et al. (2001)also reported that 18 vaccinated and 20 control pigs died of causes unrelated to vaccination or to cysticercosis and were excluded from the study. Morales et al. (2008) worked in a community in Mexico where 70% of the farmers kept the pigs for commercial purposes, lack of an alternative for these farmers when their pigs were recruited for the study may have led to high loss to follow-up since farmers depended on the pigs for income and would have to sell them.

Socio-economic factors

Although suitable trial designs will have been chosen for their methodological rigour, socio-economic context may necessitate opting for modified designs. For example, Steinmann et al. (2011), on evaluating the efficacy of single-dose and triple-dose albendazole and mebendazole against soil-transmitted helminths and *Taenia* spp., the costs associated with double-blind trial implementation were deemed inappropriately high and an open label trial design with the outcome assessors blinded to ensure validity was chosen as a more appropriate design for the context.

Cultural factors

Li et al. (2012) tested the use of pumpkin seed and areca extract to treat taeniasis and found that it was effective in expelling whole tapeworms but with some transient and well tolerated side effects in 46.3% of the study subjects. Cultural context played a big role in this study where the importance of traditional medicines over modern medicine in Chinese communities supported uptake of the intervention.

Uptake of health education interventions is often influenced by gender and education level; consequently, choice of participants and scheduling of the training sessions, should consider them to ensure representativeness and avoid bias. However, though the study by Ertel et al. (2017a), was not explicit on these contextual factors, the results indicated that neither gender nor educational level influenced knowledge uptake showing that design may overcome cultural factors that would otherwise constrain uptake.

Service and organization factors

Jayashi et al. (2012) worked with district level partners and a national university in the implementation of a study in Peru to test a combination of two recombinant antigen vaccine TSOL16 and TSOL18. Sensitization of the target community was achieved through individual household visits resulting in community support of the intervention.

> *"In Peru everybody recognizes The National University of San Marcos so that was useful. So if you say you are coming from The National University of San Marcos they all know and that is a good point [in gaining entry to the community]..[because the university is]well recognized"* KII06.

In the study by Li et al., (2012), appropriate sensitization and the participation of the local County Centres for Disease Control (CDC) supported the success of the project.

3.3.5 Contextual factors in effectiveness studies

Effectiveness studies are performed under "real world conditions" and those identified for *T. solium* control were predominately community based, although some of the characteristics overlap with those of efficacy studies (Singal et al., 2014).Twenty-eight studies focused on testing the effectiveness of various intervention technologies or a combination of interventions. The impact pathways of these research projects were to demonstrate effectiveness in the medium term and demonstrate their use in programmatic settings to achieve sustained impact. These studies included anti-parasitic treatment of people, pig replacement and mass screening (Garcia et al., 2016a). Implementation of health education (Alexander et al., 2011; Beam et al., 2019; Mwidunda et al., 2015; Ngowi et al., 2011;Ngowi et al., 2008; Ngowi et al., 2007; Ngowi, Mlangwa, & Mlozi, 2009)and treatment of humans with niclosamide (Allan et al., 1997; O'Neal et al., 2014), praziquantel and niclosamide (Keilbach et al., 1989). MDA in humans with albendazole (Ash et al., 2017; Okello et al., 2016; Steinmann et al., 2011, 2015), praziquantel and niclosamide (Alexander et al., 2011), and MDA with praziquantel alone (Braae et al., 2017; Camacho et al., 1991; Cruz et al., 1989a;Sarti et al., 2000). The treatment of pigs with oxfendazole (Kabululu et al., 2018; Pondja et al., 2012) MDA with praziquantel in humans combined with dosing of pigs with oxfendazole (Garcia et al., 2006), and the vaccination of pigs with TSOL18 vaccine combined with dosing with oxfendazole (Assana et al., 2010). The contextual factors are discussed below and summarized in Table 3.3.

Table 3. 3: Summary of contextual factors analysis for effectiveness studies

Contextual factor	Specific examples from the studies	References and country of focus
Epidemiological factors	○ Baseline prevalence of the disease could modify the goal of the project and measures of effect ○ Loss to follow up was a major challenge	(Ash et al., 2017; Bardosh et al., 2014) in Lao PDR
Socio-economic factors	○ Baseline knowledge can affect delivery and evaluation ○ Motivation to rear pigs and importance of pigs in the community can influence adoption ○ Language for delivery of especially education messages should considered. ○ Baseline anthropological studies to understand the socioeconomic and cultural characteristics of target community are important	(Hobbs et al., 2018) in Zambia, (Bardosh et al., 2014) in Lao PDR
Cultural factors	○ Baseline anthropological data on beliefs, attitudes and practises which may help maintain *T. solium* transmission within a community and which may be hard to change can help understand and mitigate risks to success	(Ashet al., 2017; Bardosh et al., 2014) in Lao PDR
Geographical and environmental factors	○ Natural and built environment can influence the implementation, for example, poor accessibility of study sites due to lack of roads, challenges in evaluation due to lack of sample handling and storage facilities ○ Seasonality of rainfall and cropping season may affect participation in interventions and may also lead to loss to follow-up.	(Assana et al., 2010; Garcia et al., 2006; Ngowi et al., 2011;Okello et al., 2016) in Tanzania, Lao PDR, Peru, and Cameroon
Service and organizational factors	○ Local capacities of staff and institutions can affect the delivery of intervention ○ Stakeholder involvement and sensitization of local communities on the activities and benefits of the project can influence the support and adoption of the interventions	(Bardosh et al., 2014; Cruz et al., 1989b; Ngowi et al., 2011) in Tanzania, Lao PDR and Ecuador

	○ Incentives to ministry staff involved in implementation are important.	
Policy and strategies on *T. solium* control	○ The approval and acceptability of drug administration interventions can be influenced by country laws on licensing of the drugs to be tested ○ Integration of T. solium control with existing disease control programs can have synergistic effect and opportunities exist to embed T. solium control within other national disease control efforts.	(Ash et al., 2017; Braae et al., 2016) In Lao PDR and Tanzania
Historical factors	○ Past involvement of target community and their experiences about other projects can shape their participation in future projects - previously beneficial projects may encourage participation in other projects	(Garcia et al., 2016b;Okello et al., 2016) in Lao PDR and Peru

Epidemiological factors

Establishing and understanding the epidemiological context of the study area is important in guiding the process of setting goals, choosing the intervention to implement, and deciding which methods and diagnostics techniques to use to measure impact. For example, in Laos PDR, where taeniasis was hyperendemic, the goal of the intervention was to lower the incidence rates with the overall goal of reducing the burden of neurocysticercosis (Ash et al., 2017).

"……we basically did a therapeutic intervention in both humans and pigs and that was the first decision; from all the control intervention which one is the most appropriate for that particular context" KII04.

The process of designing interventions at scale including the calculation of sample-size, unit of randomisation may be enhanced using transmission models. Several models specifically for *T. solium* transmission have been developed which include EPICYST model (Winskill et al., 2017), CystiSim (Braae et al., 2016), decision tree model (Gonzalez et al., 2009) and the Reed frost stochastic model (Kyvsgaard et al., 2007) as comprehensively reviewed by Dixon et al. (2019).

As was the case with efficacy studies, loss of participants (both porcine and human) to follow up has been cited as a major challenge during evaluation by many of the primary studies due to the reduction in sample size. Failure to have plans in place to adjust for the changes in sample size during evaluation could put the validity of the results into question impairing the effect or impact of the intervention. In the study by Ngowi et al. (2007) in Tanzania on the financial efficiency of health education, seasonal availability of feeds led to 52% drop out of the baseline farmers. Timing for baseline surveys should be done to adjust for fluctuations in prevalence due to seasonal confinement of pigs following the cropping seasons. This will ensure evaluations are based on the correct base prevalence as was recommended by Kabululu et al. (2018) and Assana et al. (2010). Additionally, outbreaks of African Swine fever in the neighbouring regions may have discouraged participation by the pig farmers with negative implications on the measurement of effect.

Assana et al. (2010) in a field trial of the TSOL18 vaccine in Cameroon compensated the farmers at the rate of 12 Euro monthly for hosting the animals during the trial and this could have averted possible high loss to follow up. In their study 28 pigs (11.6%) out of 240 pigs (10 from the vaccinated group and 18 control) were unavailable during the evaluation. To remedy the challenge of loss to follow up statistical analyses have been used for adjustment to ensure representation as was done in Morales et al. (2008) and Assana et al. (2010).

Socio-economic factors

Social and economic factors have far reaching effects on the delivery and sustainability of intervention programs. The motivation for rearing pigs and the relative importance of pigs in the community can influence their participation and adoption of *T. solium* control interventions. In Peru, O'Neal et al. (2014), observed that the community had a lot of interest in the control of *T. solium* possibly because they kept pigs for income generation. Steinmann et al. (2015) noted the high cost of constructing a toilet ($300) in a village in China which could have affected the sustainability if farmers cannot afford after the end of the project. In Tanzania, Kabululu, noted that the use of local construction materials like tree poles, gravel and timber was encouraged to construct pig pens. The project ensured farmers provided free labour during construction to encourage participation and enhance learning. Interventions targeting building of sanitation or animal husbandry infrastructural facilities should emphasize the use of locally available construction materials to ensure sustainability of the program.

Findings relating to economic barriers to control, strengthen the call for conducting ex-ante and ex-post economic analysis. Cost-benefit or Cost-effectiveness analysis can be used to identify the costs and benefits (financial, health or societal) accruing to different stakeholders. Narrod et al. (2012)proposed the modified risk analysis framework which utilizes stakeholder engagement throughout the process to help assess the societal cost of zoonotic diseases to all sectors involved in control. Examples exist on how to understand the societal costs and benefits of intervention or surveillance of zoonotic diseases which allows for appropriate cost-sharing scenarios to be considered based upon the benefits accruing to the veterinary or human health sector, or across the public or private space(Roth et al., 2003).

Immigration of people may pose a threat to the sustainability of the elimination campaigns due to the possibility of re-introduction of infection where people with taeniasis may migrate into diseases free areas as was the case in Tumbes, Peru Garcia et al. (2016b). Pigs and pork with cysts could also be transported into areas that have achieved eradication. A well-functioning surveillance system operating at the community level has, however, been recognized as a potential solution to this threat. Furthermore, economic policies (e.g. bilateral laws penalizing cystic meat) operating at national level can help drive adoption of *T.solium* control interventions and prevent reintroduction of infective material as was noted by Bardosh et al. (2014).

Cultural factors

Cultural factors particularly beliefs, attitudes and practices including religious beliefs may influence the effect of the interventions and they are often deep rooted and hard to understand and change. For example, in Lao PDR, the study village had religious significance of consumption of raw pork during ceremonies throughout the year (Ash et al., 2017; Bardosh et al., 2014). These practices may maintain transmission within the community even with *T. solium* control interventions being implemented. Cultural belief and taboos especially on toilet use have been shown to be a barrier to adoption of behaviour change messages in studies in China and Zambia (Bulaya et al., 2015; Steinmann et al., 2015)

Very few studies carried out an anthropological study prior to implementation of the control programme to understand the sociocultural context and the knowledge attitude and practices of the participants. Okello et al. (2016) had a medical anthropologist in the team who helped understand the sociocultural and economic characteristics of the target community in Laos PDR. They found that transmission was influenced by social determinants including limited market access, interrelationships between alcohol, ancestral sacrifices and the consumption of raw pork, seasonal variations and poor latrine coverage (Bardosh et al., 2014). In a later study, the same author also described the need to understand the local community while discussing the effectiveness of neglected tropical disease interventions under the social difference and community agency domain of the anthropological framework to improve effectiveness of NTD interventions (Bardosh, 2018).

> *"we did some social research because we had a medical anthropologist in the team who did a lot of the background sort of focus group discussion with people [to understand them and get their inputs]"* KII04.

Rapid assessment techniques can be used to understand the social determinants which may affect the success of *T. solium* control interventions (Bardosh et al., 2014; Manderson & Aaby, 1992). These preliminary studies will also help in making the right choice of the intervention to implement which fits in to the local sociocultural settings. Ngowi et al. (2011) noted that few women attended the training session of the health education intervention despite being the ones who rear pigs due to their commitment in their farms at the time of the training sessions raising question of reach of the education campaign due to differential gender roles.

Keilbach et al. (1989) in a study in a Mexican village noted that high illiteracy levels made it hard for people to give up traditional practices which exacerbate *T. solium* transmission. This may require interventions geared towards behavioural change. Extensive behavioural and anthropological studies to guide the design of health education intervention to prevent failure to change behaviour as was the case in (Ngowi et al., 2008; Ngowi et al., 2007; Ngowi, Mlangwa, & Mlozi, 2009) may be necessary. Although, Hobbs reported that delivery of an educational intervention required only a laptop, projector and small generator, this technology may act as impediment to uptake in some areas where computer skills may be lacking even among government officials.

Language can also impact the delivery of health education intervention and evaluations of data collection instruments and training materials are not understood by the respondents. In the preliminary evaluation of the computer-based *T. solium* education program '*The vicious worm'* by Hobbs et al. (2018), participants failed to understand the connection between ingestion of invisible tapeworm eggs and human NCC due to use of complex language. However, the study used a unique approach where the epidemiologic and economic evidence of the impact of the parasite were discussed by the workshop participants and provided an opportunity to re-examine the life cycle and leading to an appreciation of its impact and endemicity. Large scale uptake and sustainability may be compromised if knowledge does not diffuse to non-participants due to use of technical language. Use of Swahili language - the widely spoken and national language of Tanzania helped in the delivery of the health education interventions implemented as reported in (Ngowi et al., 2008; Ngowi, Mlangwa, & Mlozi, 2009) The pork tape worm life cycle is not easy to understand, even if simplified and non-technical language is used, and general visualization through pictures can also help deliver the message to communities with low literacy levels.

Geographical and environmental factors

Geographical and environmental factors also play a role in supporting or influencing the success of *T. solium* interventions by affecting coverage and uptake. In Ngowi et al. (2011) study, few women attended the training sessions raising questions of reach because they were busy in the farms during the intervention period as it was planting season. The authors acknowledged that most pigs were reared by women thus their inability to participate, adversely impacted on the effect of the health education intervention. Aspects of the natural environment may limit access to some study sites in places where road infrastructure is not well developed. Additionally, it may create a conducive environment for transmission in places where un-boiled drinking water from natural sources is used. For example, in Lao PDR, some study villages were unreachable for over 6 months during the rainy season as reported in (Ash et al., 2017) and two of the 11 key informant respondents. Garcia et al. (2006) indicated that the choice of the study site was influenced by accessibility by road and the proximity of the site to the city where specimen handling, centrifugation and storage facilities were available. To adapt to this challenge, implementers may decide to have their own sample handling facilities or plan the field visits to fall in times of the year when the roads are passable as was done by Ash et al. (2017) and Okello. At times the purposive choice of study site may introduce bias, but it could be the only possible way out to allow implementation with limited resources and time.

Contextual factors can also affect the evaluation process hence compromising the measurement of effect or impact. For example in Sarti et al. (2000), seasonal variation in agricultural activities based on rainfall patterns in the study area, led to more males attending the baseline meetings than the post-intervention meetings. This compromised the gender analysis of the effect of the interventions. Perhaps generating a community map of annual and daily calendar of activities, could have led to a more appropriate timing of meetings to avoid non-participation.

Service and organizational factors

Service and organizational context including local capacity in terms of availability of qualified staff to carry out the project activities was also considered vital. All the KII respondents reported that working with the local ministry officials was mandatory for successful implementation. However, the officers needed to be sensitized on project goals, objectives, and activities as part of building capacity for the interventions. This was reported by 9 out the 11 KIIs and 4 articles presented in detail how they involved local staff from the relevant ministries(Cruz et al., 1989b; Garcia et al., 2006; Sarti et al., 2000; Steinmann et al., 2011). The involvement of local ministry staff is a necessity to ensure cooperation and participation. However, there is need to coordinate project activities and other ministry activities as to avoid conflict between them, as was observed by Ngowi et al. (2008).

"The medical guys we worked with were really smart and some were doing their masters online and were really willing and clever. We didn't have to bring anybody from outside, the project team went there, and we conducted training to their medical staff and animal health workers to train them on the specific of the sampling and we were very confident that they were able to do everything we required… So, staff capacity was brilliant" KII11.

It was indicated by key informants that government employees involved in the implementation required incentives which may be of two types – per-diems and non-monetary incentives. Ten (10) out of 11 key informants agreed that donor funding must budget for provision of per-diems and other field allowances to ministry of livestock and ministry of health staff working on the project. This has been the practice in many African countries where the ministries are in most cases under-funded and development projects are donor funded in many instances. This position has been supported by Bardosh, (2018) who discussed the need for providing incentives to field staff in the effectiveness of neglected tropical disease interventions framework.The non-monetary incentive included building capacity of the local staff. The additional skills acquired through short training and higher levels of training like post graduate studies may help in advancing their careers. Many projects had this component: in form of competitive masters and PhD degree scholarships.

"We have a formal capacity building in the projects in form masters and PhD students, but we also do a lot training. So district people were taken care of over the project period which was over 6 years" KII04.

'When we work with them, we give them per-diem as per the government rates but when we finish, we don't continue giving them because we will not have the funds, so the issue of sustainability comes in [when donor funding run out]" KII09.

Lack of technical capacity may have led to problems in sample handling and management. Sample labelling and inventory especially for large scale projects may lead to reduced power to detect an effect if some samples were lost affecting evaluation.Ash et al. (2017)experienced high number of faecal samples which were unidentified pointing to the need for a well-organized sample recording and tracking especially for large scale interventions.

Infrastructural aspects such as laboratories and cold chain were better considered early during the project inception as reported by 6 out of the 11 KIIs. In the study by Okello et al. (2016) in Lao PDR the lack of facilities made it impossible to carryout large scale carcass dissection of pigs as part of the evaluation process. In Peru and Zambia long term funded projects led to the establishment of laboratory and other related research facilities in the study sites which may have had a positive impact on the project. Lack of laboratory facilities and unreliability of the diagnostics techniques has often been cited as a big impediment to the evaluation of *T. solium* control interventions (Ngowi et al., 2008).

> *"In Peru at the field site we have administrative facilities, and we have animal kraals and we have a clinic, CT scanner, a lab- we have all that capacity"* KII02.

> *"the project was able to put up a small lab in the area, just a simple structure with a power generator"* KII-11

> *"What is on the ground, what structures are there, and I think that should define all that you are going to implement"* KII01.

Institutional stakeholder involvement

For *T. solium* control interventions, a variety of stakeholders were identified from by the KIIs and primary research articles as being vital for the successful implementation. They included national government ministries and agencies (ministries of livestock and health, research approval commissions, and One Health coordinating unit) if present. At the project site level, local government officials, community leaders, community members including diseases victims and community-based organizations (CBOS) should be represented. Also, local, and international NGOs, academic institutions (universities and local schools), and pharmaceutical companies are important. For example, extensive involvement of appropriate local stakeholders in peer learning and planning in Peru led to over 90% of the local people supporting the project(Beam et al., 2019; Cruz et al., 1989b).

Specifically, involvement of local governments and community leaders was also emphasized in papers and by key informants. These include the district level representatives of the national government and the local community leaders like the mayor and chiefs depending on the local administration organization in the target country. Thizy et al. (2019) points out that stakeholder engagement can help in shaping the implementation pathways and should start at project onset and maintained throughout the project life cycle. The most common approach was holding one on one meetings with community members to explain the goals and objectives of the project and address any concerns they had about the project. The selection of stakeholders should reflect the specific nature of problem to be addressed (OECD, 2020) and the context within which implementation is to occur (Hitziger et al., 2018).

> *"I introduced myself to each community leader in the villages so that was very important just to know where I was [with respect to location with their area of administration] and what I was doing"* KII06.

> *"As a hierarchical society we made sure to get the village headmen and area chiefs on board because I think we were able to leverage that sort of hierarchical structure and if you convince*

the area chief on the importance of the intervention, they actually do have a lot of weight in getting people to adhere to those" KII11.

In nearly all the studies the ministry of livestock, particularly the department of veterinary services was involved at the implementation stage where the department provided officers to help in carrying out project activities. This could be attributed to the fact that majority of the interventions – even those focused on human host, measure the outcomes at the pig level due to the ease in obtaining samples and availability of diagnostic techniques.

"We always had the support of the veterinary side so the agricultural side was always on board and the human side are not sold on the idea of One Health I think particularly on zoonotic diseases and this is a barrier to getting the ministry of health on board" KII10.

The ministry of health was majorly involved when the intervention was targeting humans. For example, the MDA programs where the local health posts and health officers were involved in administering the drugs and managing side effects (Ash et al., 2017; Steinmann et al., 2015).

The development of a truly 'One Health' control program demands for the cooperation and participation by the veterinary, medical and public health sectors and the success of these programmes calls for the attention to the management and coordination of the various components of these control organization as alluded by Murrell & Pawlowski, (2006). To truly embrace the One Health concept, gaining buy-in and collaboration from the ministry of health at an early stage, even when only non-human hosts were being targeted for intervention, would be more appropriate. Thus, participatory approaches of including actors from the human health and veterinary sectors as well as local communities and local authorities to facilitate knowledge exchange should be considered to encourage stakeholder engagement (Hitziger et al., 2018; OECD, 2020; Zinsstag et al., 2005)

Two out of the 11 key informant respondents cited the involvement of the actual people affected by the disease as helpful in delivery of the intervention. For example, having people who have been affected by either taeniasis or neurocysticercosis as community volunteers can help make the problem feel more real. This could in turn lead to community support for the proposed initiatives.

> *"[people can see] …this is a big worm ..and then of course where you have cysticercosis the people are afraid of the seizures [and] they are afraid of the consequences of cysticercosis. if you have cases of people who volunteer to be presented as affected then you can explain the connection between the people they see who have the seizures and the worm ..this may have a lot of power to convince the people do something[due to fear of consequences]"* KII03.

> *"….there are many other people who have just been affected by the disease, a family member has cysticercosis , the pigs are sick [may be with other diseases] or they[people] have taeniasis and they [may] become quiet motivated to stay engaged to talk to their neighbors [about the problem] , I think the trick is in identifying those people and giving them a capacity to work and share what they know"*KII02.

Policy and strategies on *T. solium* control

Policy, strategies, and legal guidelines in a study country can affect the choice and delivery of intervention since they must be embedded within the country laws and guidelines. In Lao PDR the ministry of health had not licensed praziquantel for use in humans and although it is the recommended drug of choice by WHO for treatment of taeniasis. This coupled with the general acceptability of albendazole by local community due to its ease in chewing made it the drug of choice over praziquantel in the MDA intervention implemented by Ash et al. (2017). The policy environment and existing country laws also influence the adherence to ethics through licensing and monitoring to prevent violations. Consideration of ethics and harm to the research participants may also influence the choice of technology to be trialled especially for therapeutic interventions, for instance, Niclosamide may be considered as a substitute for Praziquantel (which can cross the blood-brain barrier and may lead to adverse effects (Camacho et al., 1991) in areas with a high prevalence of NCC (Allan et al., 1997; Okello et al., 2016).

Historical factors

Historical factors, for example influence of past involvement of target community in disease control interventions, positive or negative experiences with certain programs can impact delivery of interventions positively or negatively. In Piura province, Peru, O'Neal demonstrated that ring screening for taeniasis could reduce *T. solium* transmission and acknowledged the excellent participation of the local community, possibly due to good rapport which has been created overtime due to continued work on *T. solium* control in the area. History of having participated in a bigger project funded by the Australian Centre for International Agricultural Research (ACIAR) made the village in Northern Lao PDR to be supportive of *T. solium* interventions (Ash et al., 2017).

Integration of *Taenia solium* control with other programmes

Leveraging the integration of *T. solium* control interventions with other country programs on control of other NTDs or wider human and animal health issues can also indirectly afford *T. solium* control the much-needed government support.

Wide-spread uptake of this approach, however, will require proof that it will be cost effective as has been shown for combined treatment of schistosomiasis and other soil transmitted helminths through school deworming programs (Braaeet al., 2016).Braae et al. (2017) in their study in

Tanzania concluded that utilizing existing National deworming infrastructure under the school deworming programmes may be cost effective approach to the control of *T. Solium* infections.

The anthelmintic treatment of people against *T. solium* and Soil Transmitted Helminths (STH) as well as treatment and prophylaxis of pigs against *T.* solium and Classical Swine Fever (CSF) in Laos, was both effective at reducing prevalence of each target disease and highly cost effective(Okello et al., 2016; Okello et al., 2018). Similar observations were made byGarcia et al. (2006) who combined human and porcine chemotherapy and vaccination against hog cholera. This approach increased the turnout of pigs sampled during the baseline survey. Jayashi et al. (2012) used a similar approach where they vaccinated the pigs against CSF alongside the TSOL16–TSOL18 vaccine to encourage more participation by the farmers in Peru.

In many countries, a lot remains to be done in terms of restructuring administrative processes in order to maximize the benefits of integration as reported by Standley et al. (2018). The potential of integrating *T. solium* control interventions with other programmes especially those focused on soil transmitted helminths and water, sanitation, and hygiene (WASH) programs was emphasized by nine out of the 11 key informant interviews.

> *"It is important we think of integrating T. solium* control *with other problems which are more recognized but are beneficial to Taenia solium also. One of the strategies is the MDA undertaken in school using praziquantel which can also take care of taeniasis…… the other one is the WASH programmes…."* KII09.

> *"Integration….it needs studies to prove that it would actually be cost efficient"*KII01.

However, implementers of combined approaches need to be careful to ensure the observed effect is attributable to the intervention under implementation and that there is no confounding with the effect of the other programmes running in the same study area. Sarti tested the effect of MDA with praziquantel on taeniasis and during evaluation they noted the increase in toilet coverage from 31% during baseline to 64%. This change was not related to any activity undertaken by the intervention under evaluation but probably to WASH initiatives within the study area.

Ngowi et al. (2008) implemented a health education intervention in an area where another NGO was issuing heifers to farmers and training them on husbandry practices. Although, the implementers blinded the participants on the objective of the study, spill over effect from the other program may have confounded the results of the evaluation of the health education intervention. Other programmes being implemented within the study site simultaneously with *T. solium* control may affect compliance. Ongoing therapeutic programs such as school deworming programs may create concern by parents that their children were being given too many pharmaceuticals, a scenario faced by (Ash et al., 2017; Okello et al., 2016; Steinmann et al., 2015). Proper coordination and information sharing across health programmes may allow a synergistic effect between MDA programmes and positively influence uptake as well as addressing some of the barriers to implementation such as conflict between the goals of different stakeholders (Hitziger et al., 2018).

3.3.6 Contextual factors in scale up or implementation research studies

Implementation studies consider the application of research findings into practice. They must emphasize partnerships between community members, implementers, researchers, and policy makers and by definition need to understand the enabling environment (Theobald et al., 2018).

Three studies identified were classified as implementation research projects which aimed to achieve and sustain long term impact. They included MDA with praziquantel under the National Schistosomiasis Control Programme (NSCP) in Tanzania (Braae et al., 2016), evaluation of the

Community Led Total Sanitation (CLTS) in Zambia (Bulaya et al., 2015) and the community based education programme developed using the PROCEDE-PROCEED model implemented in Burkina Faso (Carabin et al., 2018). The three studies had substantial government support in terms of buy-in and policy orientation which ensured active involvement of the local levels of government which has been identified through the key informant interviews as a major constraint to successful implementation of the interventions. The contextual factors are discussed below and summarized in Table 3.4.

The three studies tried to identify the contextual factors which may have affected the implementation of the interventions and tried to adapt to emerging contextual issues during the project life cycle to a greater extent than studies within the previous categories. Bulaya et al. (2015) conducted a preliminary evaluation of the effectiveness of the CLTS program in reducing the prevalence of taeniosis and porcine cysticercosis in Eastern Zambia, eight (8) months post intervention, there was no reduction in PCC prevalence. Some of the cited reasons for this included continued open defecation practice possibly due to their cultural practices. Culturally, household male members of different age groups and relationships among the Chewa people of Eastern Zambia, do not share toilets.

Table 3. 4: Summary of contextual factors analysis for scale-up studies

Contextual factor	Specific examples from the studies	References and countries of focus
Epidemiological factors	○ Problems with compliance have been observed for collection of faecal and blood samples. ○ Reduction in compliance over the lifetime of the project leads to reduced power to measure effect size. ○ Enhanced compliance for collection of faecal samples has been achieved by having a system to discretely submit the faecal samples.	(Braae et al., 2016; Bulaya et al., 2015) and (Carabin et al., 2018)
Social and economic factors	○ Differential participation of men in baseline and end line surveys due to commitments in farms may have affected gendered analysis of the effects of the intervention. ○ There was poor knowledge of cysticercosis in area - prior knowledge of this could have led to redesigning of the intervention to include health education	(Bulaya et al., 2015) in Zambia; (Carabin et al., 2018)
Cultural factors	○ Taboos around toilet use among the Chewa people in Zambia ensured open defecation continued even with promotion of toilet use. ○ Some communities may rigid to change and hierarchy in decision making may affect adoption	(Bulaya et al., 2015) in Zambia
Geographical and environmental factors	○ Rainfall seasonality affected men attendance to post intervention evaluation meetings because they were busy in the farms. ○ Other economic activities e.g. mining may affect participation in research projects.	(Bulaya et al., 2015) in Zambia and (Carabin et al., 2018) in Burkina Faso
Service and organization factors	○ One health aspects of involving all relevant stakeholders were not fulfilled leading to several challenges in the study in Zambia.	(Bulaya et al., 2015) and (Braaeet al., 2016) in Tanzania, (Carabin et al., 2018) in Burkina Faso

	○ Holding extensive community meetings which led to support for the project. ○ Finding qualified staff willing to work in field conditions under the low salary was a challenge	
Policy and strategies on T. solium control	○ Projects can be embedded within existing National disease control programme	
Financial	○ Stability and sustainability of funding may affect evaluations due to reduced sampling rounds or sample size	(Carabin et al., 2018) in Burkina Faso

Thys et al. (2015) specifically investigated the cultural contextual factors impacting the result of this intervention and made a similar observation that men among the Bantus were reluctant to use toilets due to taboos relating to sharing of the toilets with their in-laws and grown-up children of opposite gender. Obviously, the planners and implementers of the CLTS programme may not have considered these cultural aspects when initiating the project. Poor knowledge of cysticercosis (only 50% had seen infested pork) observed in this study suggests that it may have been prudent to have implemented a health education intervention alongside the CLTS project or any other intervention as suggested in(Ngowi et al., 2008; Sarti & Rajshekhar, 2003).

Braae et al. (2016) evaluated the effect of repeated MDA plus track and treat of taeniosis cases on the prevalence of taeniosis in Tanzania. The study presented limited information on the various contextual factors they considered in the planning and implementation, or which may have posed challenges to the project. However, the authors report that extensive community meetings were held to sensitize the target community about the project. To build trust and ensure the MDA intervention was supported by the target population, a mechanism was put in place to report adverse effects from the anthelmintic to the district health officer or the assigned medical doctor. The project team also reduced embarrassment around the submission of faecal samples by providing containers for sample collection and setting up strategic locations for drop off therefore improving compliance to some degree. Compliance did eventually decline however, reducing the sample size towards the end of the study which made it difficult to measure the impact of the MDA among school age children on *T. solium* prevalence, a significant deviation from the set goals of the study.

Lastly, Carabin et al. (2018) implemented a cluster-randomised controlled trial to measure the effectiveness of a community based education programme on cumulative incidence and prevalence of human *Taenia solium* cysticercosis in Burkina Faso. The study used implementation research approach with extensive community involvement in the project and a strong partnership with local organizations to successful implement a programme. Water and Sanitation for Africa, a local NGO provided experts who trained facilitators on Participatory Hygiene and Sanitation Transformation (PHAST) model which was the hangar of the project (Clark et al., 1996).

A comprehensive anthropological study during the project inception, to fully understand the social structures and norms of the target community was not carried out, which resulted in several challenges. The hierarchal nature of one of the communities made that decision are made at the top by the community leaderships and passed on to the general population. This led to poor adoption of the intervention possibly because the population felt left out in the decision-making process. The need to fully engage community level actors and create a collaborative environment between them and the scientific community in order to build trust has previously been highlighted by Hitziger et al. (2018). Additionally, there was refusal to provide blood samples by some of the community members citing the insufficient token of appreciation offered. This may have affected the evaluation of the project and may have been avoided by involving the target participants in deciding on the token to be offered, although this must be balanced against the ethical issues surrounding ‘payment’ of participants for engaging with a research programme which might diminish the sense of autonomy a participant feels in providing informed consent. Other sociocultural factors like the rigidity of the communities to behavioural changes were also cited in this study where it was hard to convince people to adopt use of latrines.

The intervention was delivered in the local language which was felt to result in improved uptake and was reinforced by the close monitoring conducted by the lead investigator and local organization staff ensuring integrity of the implementation. The program identified a challenge in finding qualified staff willing to work in field conditions under the low salary provided by the project. This can be avoided by conducting pre-visits and holding meetings with the relevant ministries so that the expectations of the local staff are considered in the budgeting process. A position supported by Bardosh, (2018) where he discussed this challenge under the strategies and incentives to staff in the socio-anthropological framework to improve the effectiveness of NTDs intervention.

Geographical context came into play within this programme, when the discovery of gold in the study area during the implementation period, caused people to leave the area to work in the gold mines leading to losses to follow-up. The project adapted to the challenge by replacing the dropouts with another member of the same family and using Bayesian modeling during analysis to increase validity of the results and to avoid bias (Carabin et al., 2018). Funding stability can also affect the implementation of a project like was reported in this study where budgetary cuts during implementation led to cancellation of one of the planned sampling rounds. The success of many NTD interventions will to a large extent be pegged on continued and sustained funding (Reed & McKerrow, 2018).

Conclusions

1. The effect of contextual factors on efficacy, effectiveness and scale-up studies vary and the factors interact to influence the implementation and evaluation of *T. solium* control projects. For efficacy studies, context is often limited to the more technical aspects of the programme; classified here as epidemiological factors, since the researchers tend to control the environment under which the studies are implemented.
2. For field-based effectiveness and implementation studies a wide range of contextual factors were found to be important in the eventual success or failure of interventions. Some of the important contextual factors identified through the literature and key informant interviews were epidemiological factors including baseline and end-line outcomes measures, socioeconomic and cultural characteristics of target participants encompassing local knowledge, attitude and perceptions, geographical and environmental factors, service, and organization including stakeholder roles and their engagement. Implementation research projects will need all these contextual factors plus a supportive policy framework to underpin the success of *T. solium* control programmes in endemic settings.
3. Although it might be challenging to fulfill all the contextual factors discussed, those considering rolling out interventions should consistently evaluate and consider these factors at the planning, implementation, and evaluation stages. A full consideration of these factors will also require an inherent consideration of the tenets of One Health principles which we believe are critical for the success of *T. solium* control interventions.

Recommendations

1. As the research agenda around control of *T. solium* progresses from effectiveness studies to implementation research, we recommend a greater focus on identifying, considering, and reporting the contextual factors and their potential influence on project impacts and outcomes. The pre-project analysis of the different domains of context at inception and planning should evolve into a written strategy for their mitigation during implementation.
2. Further studies are needed to generate evidence on the contextual factors operating in the various endemic regions and the expectations of communities regarding the implementation *T. solium* control intervention. Evaluation of *T. solium* control projects against the One Health principles as proposed in the blueprint by Rüegg et al. (2017) and used by Paternoster et al. (2017) is also required.

CHAPTER FOUR

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CO-INFECTION OF PIGS WITH *TAENIA SOLIUM* CYSTICERCOSIS AND GASTROINTESTINAL PARASITES IN KAMULI AND HOIMA DISTRICTS, UGANDA

ABSTRACT

A study was carried out in Kamuli and Hoima districts in Eastern and Western regions of Uganda to determine the *Taenia solium* porcine cysticercosis (PCC) and gastrointestinal (GI) parasites co-infection status in pigs. One hundred and sixty-one households were selected randomly and visited between November and December 2019. A household questionnaire was administered, and fecal and blood samples were collected from at least one pig older than three months per household. A blood sample was obtained from a jugular venipuncture and a rectal fecal sample was obtained. *Taenia* spp. circulating antigen levels in the sample sera was tested using a commercial enzyme-linked immunosorbent assay kit, apDia™ cysticercosis Ag ELISA. The modified McMaster technique was used to identify and quantify the GI parasites. The apparent animal level seroprevalence for PCC was 4.8% (95% CI 2.7 – 7.1) and differed across the two districts (P = 0.018). At the pig herd level, the prevalence was 9.7% (5.5 – 14.4). The prevalence of the different nematode eggs and coccidian oocysts in the two districts were as follows: Strongyles 79.0% (95% CI 74.3 – 83.6), Coccidia 73.3% (95% CI 68.3 – 78.6), *Trichuris* spp. 7.4% (95% CI 4.9 – 10.6), *Strongyloides ransomi* 2.1 (95% CI 0.7 – 3.5), *Ascaris* spp. 4.9 (95% CI 2.8 – 7.4). Overall, across the two districts, the arithmetic mean for the oocysts per gram (OPG) for coccidia was 2042.2±5776.1 and eggs per gram (EPG) was highest in strongyles 616.1±991. Overall, 57.4% of the porcine cysticercosis seropositive pigs were also positive for at least one of the gastrointestinal

helminths, which included strongyles, *Strongyloides ransomi*, *Trichuris* spp. and *Ascaris* spp. Pig age and having a handwashing facility near toilet were significant predictors of PCC animal-level seropositivity while district was a significant predictor for co-infection of GI parasites with PCC. The knowledge that pigs could be infected by *T. solium* by eating dirt feeds was significant predictor of herd-level PCC seropositivity, OR 5.5 (95% CI 0.7 - 43.8) p=0.005. The co-infection status of pigs with both PCC and GI parasites demonstrated by this study can provide an incentive for integrating the control and management of both parasites with oxfendazole. Further studies are required to understand the feasibility of using oxfendazole, including cost-benefit analysis and the acceptability by local stakeholders for the control of *T. solium* cysticercosis and gastrointestinal parasites in pigs.

4.1 Introduction

In Uganda, the production and consumption of livestock and livestock products have been growing rapidly, with the greatest growth observed in the pig sector (Twine and Njehu 2020). The establishment of piggeries and increased pig production by rural farmers is encouraged by the government and forms part of the central government agricultural plan (Waiswa et al., 2009). The pig sector is generally underdeveloped, although it has high growth potential, given the rising demand for pork domestically and in neighbouring countries such as South Sudan, Rwanda and the Democratic Republic of Congo (Ouma et al., 2017). Uganda has the highest per capita pork consumption in the East African region, at 3.4 kg per year (FAOSTAT, 2021). Pig enterprise supports the livelihoods of up to over 1.1 million households (MAAIF and UBOS, 2008). Pigs are preferred over other livestock species due to their high reproduction rate with high fecundity per reproduction cycle. This makes pig production important for income generation to meet different household financial needs (Ouma et al., 2015). Additionally, pigs act as a source of saving/‘piggy bank' to be sold in times of financial distress, mostly to pay school fees and hospital bills (Ouma et al., 2015;Ouma et al., 2014).

Despite the pig production enterprise being an important source of livelihood for the rural smallholder farmers in Uganda, animal health issues including; *Taenia (T.) solium* cysticercosis, gastrointestinal parasites and African Swine fever (ASF) pose a significant risk to the growth of the sector and negatively impact on pig and human health (M. M. Dione et al., 2014). Porcine cysticercosis, caused by the larval stage of *T. solium*, does not cause productivity constraints but contributes to perpetuating the parasite's life cycle, which causes severe neurological disease in humans in endemic settings. Pigs are the intermediate host for *T. solium* parasite. They acquire the infection through ingesting viable eggs, excreted during defecation with a human infested by the adult stage of the tapeworm as the pig scavenges. The eggs may also contaminate feed, water and the environment (García et al., 2003). This parasite is endemic in sub-Saharan Africa, imposing ever-increasing human health and economic burden with increased pork consumption (Havelaar et al., 2015b; Zoli et al., 2003). The parasite thrives in these settings due to the increasing popularity of raising pigs mostly under an extensive system of production coupled with poor sanitary conditions (Braaeet al., 2015; Phiri et al., 2003).

Despite the availability of proven simple ways to break the *T. solium* life cycle, the parasite remains largely uncontrolled in Uganda. The lack of control appears to be due to a lack of awareness of the public health implications and competing priorities with other gastrointestinal parasites and ASF that directly impact farmers' income and livelihood (Kungu et al., 2015). Whilst *T. solium* is a parasite of public health importance, GI parasites impose an additional, day-to-day chronic burden on pig keeping households through reduced productivity. At the same time, some are zoonotic and of public health importance (Nejsum et al., 2012). Pig farmers acknowledge the need to control GI parasites through deworming to improve growth and weight gain (Dione et al., 2014; Thompson, 2017). This could provide an opportunity to integrate the control of GI parasites with the control of PCC.

The most prevalent gastrointestinal helminths in Africa and reported in Uganda are from the following taxa: *Ascaris* spp., *Strongyloides* spp., strongyles *(Oesophagostomum dentatum* and *Hyostrongylus rubidus*) , *Trichuris* spp., Coccidia (Nissen et al., 2011; Roesel et al., 2017). Infection of pigs with these parasites may reduce daily feed intake, weight gain, feed conversion efficiency and overall carcass quality (Kipper et al., 2011; Knecht et al., 2011; Ózsvári, 2018). In addition, the condemnation of livers resulting from ascariasis and mortality in piglets due to coccidia infections can reduce the pig enterprise's profitability (Ózsvári, 2018). *Ascaris suum* and *Trichuris suis* are also known to have zoonotic potential and are therefore of public health concern (Nejsum et al., 2012).

The control of both *T. solium* cysticercosis and GI parasites in pigs requires changes in pig husbandry practices to avert the risk of exposure to infective materials and the judicious administration of anthelmintic drugs. The administration of oxfendazole at 30mg per kg effectively kills *T. solium* cysts and has also been demonstrated to control *A. suum*, *Oesophagostomum* spp., *T. suis* and *Metastrongylus* spp.(Alvarez et al., 2013; Mkupasi et al., 2013). Integrating such strategies as oxfendazole dosing with health education, improved pig housing and feeding may support *T. solium* cysticercosis control and at the same time improve pig production profitability through the control of pig GI parasites. The objectives of the current study were to i) to estimate the prevalence of PCC, gastrointestinal parasites, and the level of co-infection in pigs ii) to assess the risk factors associated with the infection with PCC, iii) and to provide the evidence base to support integrated control of pig gastrointestinal parasites as an integral aspect of *T. solium* cysticercosis control.

4.2 Materials and methods

4.2.1 The study area

A cross-sectional survey was conducted in Kamuli and Hoima districts, Uganda, from November to December 2019. Uganda is a landlocked country located in East Africa and lies across the equator, about 800 km inland from the Indian Ocean. It has a landmass of 200,523 square km of 241,551 square kilometres (Uganda Bureau of Statistics, 2016). Uganda is divided into districts, counties, sub-counties, parishes, and villages (Uganda Bureau of Statistics, 2018). Kamuli district is in the lowland areas of eastern Uganda at an average altitude of 1066 m above sea level. Hoima district is in the Northwest at an average altitude of 1122 m above sea level has bimodal rainfall distribution with long and short rain seasons. These districts have high proportions of pig rearing households (5 - 17% and 30 - 42% for Kamuli and Hoima district, respectively). In terms of pig numbers,Hoima has 104,669 pigs and Kamuli district 55,239 pigs (MAAIF and UBOS, 2008) and have a high demand for pig meat and pig products (Ouma *et al.,* 2017).

4.2.2 Study site and household selection

The study focused on the districts of Kamuli and Hoima, which were sites for the International Livestock Research Institute (ILRI) led Uganda Pig Genetics project (UPG) which formed basis for entry to the study sites for the current study. The districts have also been a focus for ILRI's research on smallholder pig value chain and the initial selection has been described elsewhere (Dione et al., 2014; Ouma et al., 2015). In Kamuli district, high prevalence of PCC have been reported before (Kungu et al., 2017) while for Hoima district, no study had been carried out on PCC. For Kamuli district, five sub-counties were selected from a total of 14 subcounties. In Hoima district, three sub-counties were Hoima district from a total of 5 subcounties. Five parishes were selected under each sub-county depending on pig population densities. Kamuli district has 81 parishes (Kamuli Local government, 2021) and Hoima district has 30 parishes (Hoima Local government, 2021). Three villages were then selected from each parish based on the number of pig rearing households thus 30 villages were included in the study across the two districts. In each of the 30 selected villages, a random sample of 7 households was drawn from the list of households generated by the veterinary officials in the district with aim of targeting 200 households (Figure 4. 1). This was derived by dividing the sample size for prevalence study obtained in section 4.2.3 by the maximum number of pigs to be sampled i.e. 3.

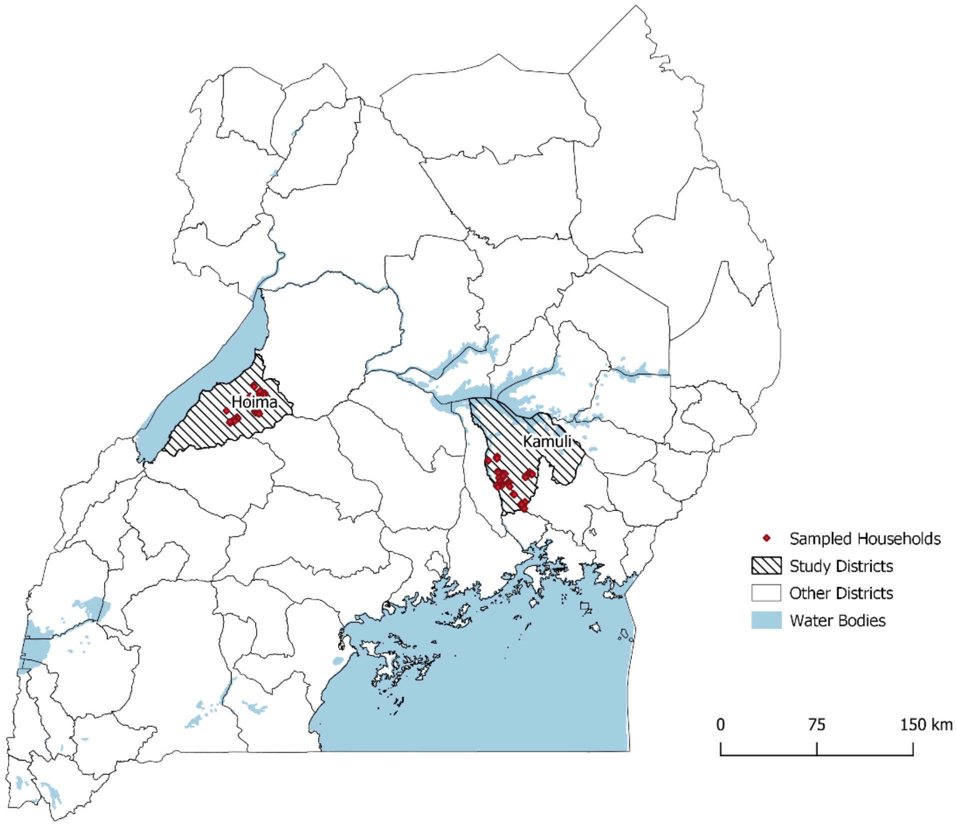

Figure 4. 1:Map of Uganda showing the study sites (Shaded) and sampled households (red dots)

4.2.3 Sample size calculation

For estimation of prevalence of PCC, the sample size calculation is based upon the expected prevalence of PCC of 25.7 % (Nsadha et al., 2014): The formula below was used as described by Dohoo et al. (2014).

$n = [Z^2Pq]/d^2$

where n is the required sample size,

Z is the multiplier from a standard normal distribution (1.96) at a probability level of 0.05, P is the estimated prevalence of 25.7 %,

q is (1 − P) that is the probability of having no disease

d is the desired precision level (5 %).

This minimum sample size was calculated at 293 pigs for PCC. Similarly, the minimum sample size, for gastrointestinal parasites study using expected prevalence of 61% (Roesel et al., 2017) and precision of 5% giving a sample size of 365 pigs.

4.2.4 Collection of household data

A household-level questionnaire was pretested, and changes were incorporated in the final version. The questionnaire was administered using Open Data Kit (ODK) to the household head, spouse or the person familiar with the running of the pig enterprise. Data were collected on self-reported and observational variables: Pig confinement (during the rainy and dry season, and during the day and night); pig water source during the dry and wet season; self-reported pig health management practices including deworming; pork slaughter and consumption practices; household hygiene and deworming practices; knowledge on *T. solium* infection; toilet availability and signs of frequent use, e.g. a clear path to the toilet, complete wall and door.

4.2.5 Pig blood and faecal sampling

Sensitization meetings were conducted at the village level a week prior to start of the survey. During the sensitization meeting the project team introduced the project and consent was sought from the farmers by signing the informed consent forms. During the household visits, pigs that were 3 months or older, not pregnant, not lactating and not manifesting overt clinical signs were sampled up to a maximum of 3 pigs per herd. If the farm had more than 3 eligible pigs, serial number were allocated to the pigs and 3 pigs selected using random numbers generated by using a random number generator app running on a mobile device.

Pigs were restrained standing using a pig snare or held in dorsal recumbency if under approximately 10 kg. Blood was collected by registered veterinary officers from the anterior Vena cava on the pig's right side (Zimmerman et al., 2012) into single BD Vacutainer® 10-ml plain tube labelled with the household and individual animal eartag number. The pigs had been ear tagged under the Uganda Pig Genetics project and the research team ear tagged the additional pigs recruited for the study. A faecal sample was collected from the rectum while the pig was restrained using the standard pig snare and samples placed in BD Falcon™ 50-ml conical tubes labelled with the animal eartag numbers. The pigs were then weighed by corralling the pig into a cage mounted on an electronic weighing scale.

At the field laboratory (a makeshift laboratory setup at the district veterinary office premises), the blood samples were centrifuged at 3000 rpm for 20 min at room temperature. The sera were then separated into two aliquots in 2-ml cryovials labelled with a unique barcode. Faecal samples were packed on ice packs and transported to the Central Diagnostics Laboratory (CDL) at Makerere University in Kampala for processing and analysis within 24 hours after collection. Serum samples were stored temporarily in the field at -20 degree Celsius and transported to CDL after 2 weeks for analysis.

4.2.6 Serology

Taenia spp. circulating antigen in porcine sera was tested using a commercial enzyme-linked immunosorbent assay kit, apDia cysticercosis Ag ELISA (ApDia, 2019) following the manufacturer's instructions. The tests were run in duplicate and optical densities (ODs) of samples measured at 450 nm with reference wavelength of 630 using a microplate reader (Biochrom®, Cambridge – CB4 0FJ, England) with the cut-off value calculated per plate as the mean OD of the negative control multiplied by 3.5. The antigen index (Ag index) of each sample was calculated by dividing the OD value of the sample by the cut off value. The cut off value was calculated as per manufacturer's instructions using the mean OD of the negative control provided in the kit. As recommended by the manufacturer, animals were classified as negative if the Ag index was ≤ 0.8 and positive if ≥ 1.3. The ELISA test used has sensitivity of 86.7% and specificity of 94.7 % (Dorny et al., 2004).

4.2.7 Gastrointestinal parasite egg identification and counts

As described by Zajac and Conboy (2007), the modified McMaster technique was used to identify and quantify coccidia oocysts, strongyles, *Strongyloides* spp., *Trichuris* spp., and *Ascaris* spp. eggs. Briefly, 4 g of fecal material was weighed and mixed with 56 ml of a saturated common salt solution. The mixture was thoroughly stirred and filtered using a tea strainer (mesh size 500-800µm). The filtrate was stirred with a Pasteur pipette and a sub-sample was picked while stirring and transferred to the first chamber of the McMaster slide while ensuring no air bubbles were left on the slide. While still stirring, the other chamber of the slide was filled, and the McMaster slide was left to stand for 5-10 minutes to allow the eggs to float. The McMaster slide was examined using the compound microscope at 10 x 10 magnification and the eggs within each grid were identified and counted. To get the total number of each type of worm eggs, the number obtained per species was multiplied by 50 to obtain the eggs per gram (EPG) and oocysts per gram (OPG) for coccidia. The results were recorded in Microsoft Excel version 2016. The method used had an estimated sensitivity of 66.67% and specificity of 81.06% (Scare et al., 2017).

4.2.8 Data management and analysis

Data was collected from 161 households in both Kamuli and Hoima districts using a semi-structured questionnaire developed and administered in Open Data Kit (ODK) (an android based data collection app loaded into smart phones). After several rounds of cleaning and merging, 144 records were complete with blood and fecal sample and a corresponding sample metadata form. A dichotomous outcome variable was computed as the presence or absence of PCC and GI parasite as either positive or negative by Ag ELISA and Mc Master slide technique, respectively to determine the prevalence.

Descriptive statistics, including the prevalence level of PCC and GI parasites and their 95% confidence intervals, were calculated using the *DescTools* and *gmodels* package (Signorell, 2020; Warnes et al., 2018). Differences in the proportions of the different variables in the two districts were tested using Fisher's exact test and P values reported. Both univariable and multivariable analyses were done using the *glmer* function of the *lme4* package in R (Bates, 2010) with village (Village ID) as a random effect to account for clustering in the sampling design.

As an initial step in selecting the potential predictors for PCC seropositivity, independent variables were tested for correlation using Pearson's chi square and Fisher Exact test, eliminating those closely correlated at $P < 0.05$. Secondly, the unconditional association was tested using Fisher' exact test to reduce the number of variables. Over 30 independent variables were tested, which included variables on pig confinement, feeding, pig water sources, deworming, pork consumption and knowledge variables. Additionally, causal diagrams or directed acyclic graphs (DAGs) were constructed in Dagitty online platform (Textor et al., 2011) to postulate the relation between potential predictors and the outcome variable (Figure 2). In the causal diagram, pig husbandry practices were directly associated with the disease status, with pig characteristics and frequency of deworming considered intervening variables. Household characteristics that encompass variables such as farmers' education and knowledge levels may also influence the outcome. In the causal diagram, we hypothesize that having knowledge on *T. solium* transmission under the household characteristics would have a protective effect on seropositivity.

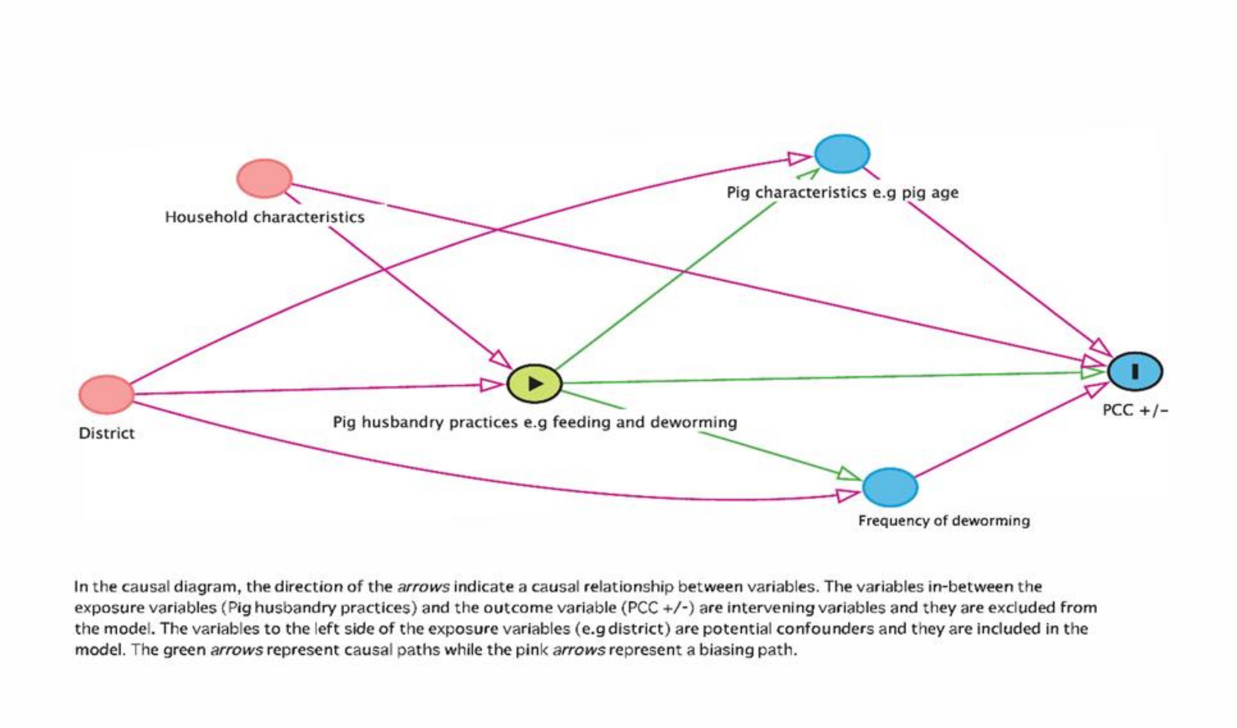

Figure 4. 2:A causal model diagram showing the potential association of predictor variables and outcome variable (positive or negative PCC)

The association of predictor variables and PCC seropositivity (negative/positive) was tested at the household level using univariable logistic regression. The models were not built at the individual level because only two variables were measured at the animal level, age and weight and they were highly correlated. Predictors with $P < 0.1$ were retained and used to fit a Generalized Linear Mixed Effects model (GLMM) with village as a random effect. All tests for significance were performed at the $\alpha=0.05$ level, and odds ratios (OR) and 95% confidence intervals (CI) were determined. The models were built by first having a global model with all potential predictors identified through the univariable modelling. The final model was then selected automatically based on information theory using the *dredge* function in *MuMIn* package in R (Barto, 2020). This methodology compares Akaike Information Criterion (AIC) for the different models and selects the least AIC. Finally, a GLMM (with village as a random effect) of the top model from the dredge analysis was fit and OR and confidence intervals calculated using sjPlot package in R.

4.2.9 Ethical statement

Ethical and animal use approval was obtained from International Livestock Research Institute's (ILRI) Institutional Research Ethics Committee (ILRI-IREC), reference number ILRI-IREC 2019-20 and the Institutional Animal Care and Use committee reference number ILRI-IACUC 2019-20, respectively. Since the study was conducted in Uganda, approval was also obtained for the Research and Ethics Committee at the College of Veterinary Medicine, Animal Resources and Biosecurity, Makerere University (reference. SBLS/HDRC/19/008) and a research permit obtained from the Uganda National Council for Science and Technology (reference A606). Written and verbal informed consent was obtained from all the study participants before commencement of the study.

4.3 Results

4.3.1 Descriptive analysis results

Demographic characteristics of the study population, pig husbandry practices and household hygienic practices are summarized in Table 4.1, 4.2, and 4.3, respectively. The majority of respondents interviewed were female (67.9% in Kamuli and 57.6% in Hoima district), and secondary education was the commonest level of education (67.1% in Kamuli and 59.7% in Hoima district) (Table 1). Blood and fecal samples were obtained from 294 pigs, majority female pigs from 144 households in both Kamuli and Hoima districts.

Description of the pig production systems

Although, the current study did not investigate the land size holding, it has been reported to be between 0.5 – 4 acres per household in Kamuli district(Ouma et al., 2015) and 2.4 – 12 acres per household in Hoima district (Mubiru et al., 2018). Under the livestock production activities in Hoima district, 4, 0.25 and 1.0 acres of land is dedicated to natural pasture, fodder and fallow, respectively (Mubiru et al., 2018). In both Kamuli and Hoima districts the household economic activities are largely agriculture based with households practicing mixed farming. Households grow food crops (soya bean, maize, sorghum, cassava, sweet potatoes, groundnuts and bananas), cash crops (coffee and sugarcane) and vegetables (cabbage, tomatoes, onions and local green vegetables).

Commonly reared livestock include cattle, goats, pigs and chicken with the position of pigs as a priority livestock among households having improved from fourth to third position (Tatwangire, 2014). In Kamuli and Hoima districts pig farmers are smallholder where pigs were fed mainly on kitchen food wastes, crop residues, especially sweet potato vines, cassava leaves and peelings, banana peelings and by-products of crops such as maize bran.

The pig value chain types in Uganda have been broadly classified into domains based on location of production and consumption. The domains include; rural-rural value chain domains (rural production areas for rural consumption), rural-urban value chains (rural production areas targeting urban consumption) and urban-urban value chains(peri-urban production areas for urban consumption)(Ouma et al., 2014). Kamuli district represents the typical rural – rural value chain domain where production is done in the rural areas for consumption in the rural areas while Hoima has a mixture of both value chain domains.

The average herd size for the two districts, including piglets, was 5.03 pigs (range: 1 – 41). The average weight and age of the sampled pigs was 22.13 kg (range 7.2 – 111) and 7.4 months (range 3 - 39), respectively. Most sampled pigs were crossbreeds between local and exotic breeds (52.4% in Kamuli and 100% in Hoima district) as determined by the farmer and research team. A recent study has shown a mix of old British and modern pig ancestries in the crossbreeds found in the study areas (Babigumira et al., 2021).

Table 4. 1: Demographic characteristics

Demographic characteristic	Kamuli % n=78	Hoima % n=66
Sex of respondent		
Male	32.1	42.4
Female	67.9	57.6
Level of Education		
Primary	6.6	0.0
Secondary	67.1	59.7
Vocational school	25.0	24.2
Technical/Diploma	0.0	3.2
University	1.3	11.3

In Kamuli district, piglets were housed (54.5%) as compared to Hoima district where more piglets (71.1%) were tethered. Most grower pigs (60.6%) were tethered in Kamuli, while in Hoima district, 26.3% were free ranging. For sows, tethering was common in both districts (58.3% for Kamuli district and 71.2% for Hoima district). Forty one percent and 27.1% of sows were housed in Kamuli and Hoima district, respectively. Hoima district had more piglets, growers and sows free ranging compared to Kamuli district albeit at lower proportions (Table 4. 2). There were significant differences in the types of confinement of the piglets and growers across Kamuli and Hoima district ($P < 0.05$, Fisher's test).

Farmers in Kamuli fed pigs maize bran (96.2 %) and sweet potato vines (44.9 %) as compared to Hoima district where 74.2% fed maize bran and 87.9% sweet potato vines. In addition, 87.9 % of farmers fed yam leaves in Hoima district as compared to 3.8% in Kamuli. The commonly used source water for watering pigs during both rain and dry season was public shallow wells at 87.0% in Kamuli and 59.1% in Hoima district. In Kamuli and Hoima district 97.3% and 98.5% respectively, of farmers indicated that they dewormed their pigs albeit at varying intervals and frequency. Overall, majority (73.1% in Kamuli and 74.2% in Hoima district) indicated they dewormed the pigs at 3-month interval (Table 4. 2).

Table 4. 2: Pig Husbandry practices

Pig Husbandry practices	Kamuli %	Hoima %
Confinement of piglets		
Free ranging	27.3	27.5
Tethered	18.2	71.1
Housed	54.5	1.3
Confinement of growers		
Free ranging	2.8	26.3
Tethered	60.6	21.1
Housed	36.6	52.6
Confinement of sows		
Free ranging	0.0	1.7
Tethered	58.3	71.2
Housed	41.7	27.1
Confinement of boars		
Free ranging	0.0	4.2
Tethered	69.2	66.7
Housed	30.8	29.2
Feed Use		
Feeding pigs on maize bran		
Yes	96.2	74.2
No	3.8	25.8

Pig Husbandry practices	Kamuli %	Hoima %
Feeding pigs with sweet potato vines		
Yes	44.9	87.9
No	55.1	12.1
Feeding pigs on unboiled swill		
Yes	56.4	57.6
No	43.6	42.4
Feeding pigs on pigweed (*Amaranthus spp.)*		
Yes	6.4	12.1
No	93.6	87.9
Feeding pigs on yam leaves		
Yes	3.8	87.9
No	96.2	12.1
Water for pigs		
Shallow well		
Yes	87.0	59.1
No	13.0	40.9
Rainwater		
Yes	57.4	6.1
No	42.6	93.9
Deworming pigs		
Yes	97.3	98.5
No	2.7	1.5
Type of anthelmintic used in pigs		
Albendazole	48.7	1.5
Levamisole	16.7	90.9
Ivermectin	10.3	0.0
I don't know	17.9	0.0
Not dewormed	6.4	7.6
Frequency of deworming pigs		
Never dewormed	14.1	6.1
At 3-month interval	73.1	74.2
More than 3-month interval	11.5	0.0
Other[a]	1.3	19.7

Other[a] - 2 months, depending on whether pig looks sick when the vet visits.

The majority (88.20%) of the surveyed households reported to consume pork either at home or in a pork joint (special butcheries in Uganda where pork is roasted and served with vegetables and drinks) (83.85%). Across the two districts, awareness of tapeworms was at 65.84% while 49.07% had heard of pork cysts or pork measles. A small percentage (6.83%) knew that pigs can get the cysts by eating human faeces. Those that thought that they get the cysts from drinking dirty water were 6.83% and 14.29% from eating dirty feed. In Kamuli district 16.7% of respondents had not dewormed themselves as compared to 45.5% in Hoima district. In Kamuli district, 57.7% and 6.1% in Hoima of respondents could not remember the last time they had dewormed themselves. However, a large proportion of children had been dewormed in school under the government mass drug administration (MDA) programs in schools; 58.8 % in Kamuli and 92.7% in Hoima district. Among the surveyed households in Hoima and Kamuli district 10.3% and 25.8% respectively, boiled drinking water. In Kamuli district, 96.2 % got drinking water from a public shallow well as compared to 72.3% of the households Hoima district (Table 3). Overall, 92.3% in Kamuli district and households had a pit latrine with 57.7% and 65.2% in Kamuli and Hoima district respectively, having no complete wall and door to provide privacy during use. Overall, it was observed that in 93% of the households there was a path leading to the toilet showing signs of use.

Table 4. 3: Household hygienic practices.

Household hygienic practices	Kamuli %, n=78	Hoima %, n=66
Last time respondent dewormed		
Never dewormed	16.7	45.5
At 3-month interval	19.2	13.6
Once a month	5.1	12.1
I Cannot remember	57.7	6.1
Others[a]	1.3	22.7
Deworming of children in school		
Yes	58.8	92.7
No	41.2	7.3
Household hygienic practices	**Kamuli %, n=78**	**Hoima %, n=66**
Boiling of drinking water		
Yes	10.3	25.8
No	89.7	74.2
Source of drinking water		
Pipe water to the house	0.0	1.5
Pipe water to the compound	1.3	3.1
Public tap	0.0	9.2
Shallow well	96.2	72.3
Surface water	2.6	7.7
Natural spring	0.0	1.5
Rainwater	0.0	4.6
Presence of latrine		
Yes	92.3	100
No	7.7	0.0
Path to toilet		
Yes	89.7	98.5
No	10.3	1.5
Complete wall/door		
Yes	42.3	34.8
No	57.7	65.2

Other[a] – Every six months, annually

4.3.2 Prevalence of porcine cysticercosis

The prevalence of PCC was calculated at both the animal and household level. The apparent animal level seroprevalence was 4.8% (95% CI 2.7 – 7.1). Animal level PCC seroprevalence differed across the two districts ($p = 0.017$, Fisher exact test). There was no significant difference in exposure to PCC between sex, age and breed of the animal ($p > 0.05$, Fisher exact test). Household level seroprevalence was 9.7% (95% CI 5.5 – 14.4) which significantly differed across the study districts ($p < 0.001$, Fisher exact test).

4.3.3 Prevalence and infection intensity of pig gastrointestinal helminths

A total of 281 pig fecal samples were examined of which 91.8% (95% CI 88.9 – 94.9) were positive for GI parasite infections. The arithmetic means for the oocysts per gram for Coccidiawas 2418±1078 in Kamuli and 1647±5540 in Hoima district, eggs per gram (epg) was highest in strongyles 684±1078, 544±889 in Kamuli and Hoima districts respectively, followed by *Ascaris* spp. 98.3±529 in Kamuli, 48.2±465 in Hoima. The EPG for *Trichuris* spp. 47.2±210 in Kamuli, 17.6±104 in Hoima district and lastly *Strongyloides* spp. 26.7±284, 2.55±29.9 in Kamuli and Hoima district, respectively. One pig in Hoima district had *Moniezia* spp. eggs (Table 4.4). There was no difference in the occurrence of the gastrointestinal parasites in the two districts ($\chi^2=0.31$, $p = 0.5$). A simple poisson regression model indicated that there was a significant difference in OPG for coccidia across age categories, with those above 7 months having a lower OPG load ($p < 0.001$).

Table 4. 4: Intensity of gastrointestinal parasites infection

	Intensity of infection (EPG and OPG)			
	Kamuli district		**Hoima district**	
Type of parasite	**Mean**	**SD**	**Mean**	**SD**
Strongyles	684	1078	544	889
**Coccidia* oocysts	2418	5987	1647	5540
Trichuris spp.	47.2	210	17.6	104
Strongyloides spp.	26.7	284	2.55	29.9
Ascaris spp.	98.3	529	48.2	465
Moniezia spp.	0.0	0.0	6.57	76.9

SD = Standard deviation, * Expressed as OPG

The prevalence of the different parasite eggs was as follows: Strongyles 79.0% (95% CI 74.3 – 83.6), Coccidia73.3% (95% CI 68.3 – 78.6), *Trichuris* spp. 7.4% (95% CI 4.9 – 10.6), *Strongyloides* spp. 2.1% (95% CI 0.7 – 3.5) and *Ascaris* spp. 4.9% (95% CI 2.8 – 7.4) (Table 5). There was a relatively high level of polyparasitism 67.2% (95% CI 61.9 -73.0, (Table 4.5). The level of polyparasitism did not significantly differ across the two districts, breed or sex of the animal (P > 0.05, Fisher exact test).

Overall, 57.4% of the proportion of PCC positive pigs were also positive for any of the gastrointestinal parasites which included Strongyles, *Strongyloides* spp., *Trichuris* spp., and *Ascaris* spp. excluding Coccidia. At species level the coinfection proportions were highest in PCC+ strongyles (57.1%). The prevalence co-infection with any GI parasite and PCCwas found to be 3.0% (95% CI 1.3 – 4.8). The coinfection of pigs with any GI parasite and PCC significantly differed across the two districts, with Hoima district having more pigs infected by both PCC and gastrointestinal parasites (P< 0.05, Fisher exact test). There was no difference in infection by sex, breed and age of pig (P > 0.05, Fisher exact test) across pigs coinfected by both PCC and GI parasites.

Table 4. 5:Animal level apparent seroprevalence of porcine cysticercosis and prevalence of gastrointestinal parasites.

	Kamuli district	**Hoima district**	**Overall, across districts**
	% Prevalence (95% CI)	**% Prevalence (95% CI)**	**% Prevalence (95% CI)**
PCC	1.9 (0.6 – 4.2)	7.8 (4.2 – 12.2)	4.7 (2.7 – 7.1)
Strongyles	81.9 (76.3 -88.3)	75.9 (69.3 – 83.2)	79.0 (74.3 – 83.6)
***Coccidia oocysts*[a]**	69.4 (62.5 – 77.4)	77.3 (70.8 – 84.3)	73.3 (68.3 – 78.6)
***Trichuris* spp.**	10.4 (6.2 – 15.4)	4.3 (2.1 – 8.0)	7.4 (4.9 – 10.6)
***Strongyloides* spp.**	3.4 (1.3 – 6.4)	0.7 (0.0 – 1.9)	2.1 (0.7 – 3.5)
***Ascaris* spp.**	6.9 (3.4 – 10.8)	2.9 (0.7 – 5.4)	4.9 (2.8 – 7.4)
Any GI parasite infection	93.0 (89.5 – 97.0)	90.5 (86.1 – 95.0)	91.8 (88.9 – 94.9)
Polyparasitism	66.6 (59.0 -74.3)	67.8 (60.5 – 76.1)	67.2 (61.9 -73.0)
Coinfection (GI parasite + PCC)	0.6 (0.0 – 1.7)	5.6 (2.8 – 9.5)	3.0 (1.3 – 4.8)
Proportion of coinfection (%)	14.2	42.8	57.4

CI - confidence interval: [a]*Eimeria spp. or Isospora suis*

4.3.4 Risk factors associated with porcine cysticercosis seropositivity

At the household level, a total of nine variables were tested using univariable model and four of them retained for multivariable modelling with p < 0.1. There was significant association (P<0.05) of household level seroprevalence of PCC with district and the knowledge that pigs can get infected with PCC by consuming dirty feed (Table 4.6). The multivariable model identified knowledge that pigs get infected by eating dirty feed as a significantly predictor of PCC animal-level seropositivity (p=0.005), OR 5.5 (95% CI 0.7 - 43.8) (Table 4.7).

Table 4. 6: Risk factors associated with household level seroprevalence of Porcine cysticercosis based on univariable logistic regression with village as a random effect.

Variable/category	Levels	Odds ratio (95% CI)	P value
District	Kamuli	1 (ref)	
	Hoima	5 (1.3 – 18.8)	0.017*
Sex of the respondent	Male	1(ref)	
	Female	1.7 (0.5 – 6.3)	0.433
Feeding pigs on yam leaves	No	1 (ref)	
	Yes	3.4 (0.9 – 13.4)	0.082
Feeding pigs on unboiled swill	No	1 (ref)	
	Yes	0.6 (0.2 – 1.9)	0.364
Deworming pigs	No	1 (ref)	
	Yes	0.2 (0.3 – 3.3)	0.262
Consumption of pork	No	1 (ref)	
	Yes	0.6 (0.1 – 3.8)	0.594
Consume pork with raw vegetables	No	1 (ref)	
	Yes	0.3 (0.1 – 1.1)	0.066
Knowledge that pigs get infected by eating dirt feed	No	1 (ref)	
	Yes	6.1 (1.4– 27.6)	0.018*
Water for pigs from shallow well	No	1 (ref)	
	Yes	2.7 (0.4 – 18.1)	0.309
Infection with any GI parasite	Negative	1(ref)	
	Positive	0.3 (0.1 – 1.5)	0.139
Polyparasitism	Negative	1 (ref)	
	Positive	0.6 (0.2 – 2.0)	0.363

*Significance level at p=0.05

Table 4. 7: Final model of household level risk factors for porcine cysticercosis on GLMM analysis.

Variables	Category	Odds ratio (95% CI)	P value
Consumption of pork with raw vegetables	No	1 (ref)	
	Yes	0.3 (0.0 – 2.4)	0.078
Knowledge that pigs get infected by eating dirty feed	No	1 (ref)	
	Yes	5.5 (0.7 – 43.8)	0.005*

*Significance level at p=0.05

4.4 Discussion

Prevalence of porcine cysticercosis

Several other studies reporting prevalence and risk factors of PCC and GI parasites separately exist for different parts of Uganda. However, to the best of our knowledge, this is the first study to report the co-infection of pigs with GI parasites and PCC to guide integrated control of both parasites. The overall apparent prevalence of PCC across the two districts (Kamuli and Hoima) was found to be 4.8% (2.7 – 7.1, 95% CI) at the individual level and 9.7% (95% CI 5.5 – 14.4) at the household level. The individual level prevalence is similar to that reported by Kungu et al. (2017a) for rural settings in Uganda which was 7.8% by HP10 ELISA and 3.0% by Apdia ELISA. This was below prevalences reported in other regions of Africa. In Mozambique, Pondja et al. (2010) reported 34.9%, Pouedet et al. (2002) reported 11% in Cameroon, Shongwe et al. (2020) reported 7% in South Africa prevalence of PCC. All studies used the B158/B60 Ag ELISA. In western Kenya, Eshitera et al. (2012) reported a prevalence of 32.8% using HP10 Ag ELISA. Although all the studies used Ag ELISA, we acknowledge that different ELISA cut off points may have been used

Although no carcass dissection was conducted as recommended by Lightowlers et al. (2016) to rule out co-infection with *T. hydatigena* in the current study, recent studies have reported no co-infection of pigs with *T. solium* and *T. hydatigena* (Braae et al., 2015;Kabululu et al., 2020) in similar endemic settings. This could be partly attributed to density-dependent immune-mediated interactions, which have been shown to prevent co-infection of pigs with both parasites (Conlan et al., 2009). However, for monitoring *T. solium* cysticercosis control interventions outcomes, Ag ELISA should not be relied upon alone due to the false positives which may result (Kabululu et al., 2020). Additionally, the prevalence of *T. hydatigena* in dogs (the definitive host for the parasite) has not been studied in Uganda. Therefore, the possibility of cross-reactivity cannot be completely ruled out.

Hoima district had a higher prevalence of PCC at the individual level compared to Kamuli district. The apparent prevalence in Kamuli was significantly lower than that previously reported by Nsadha et al. (2014), who reported a prevalence level of 28.1% (n=63) by HP10 Ag ELISA. The sensitivity of this method is 89.5% and specificity of 74% (Porphyre et al., 2016; Thomas et al., 2016b). The low specificity of ELISA tests used may have resulted in high levels of false positives, and the apparent prevalence determined by HP10 ELISA seems to be often higher than those by B158/B60 Ag ELISA (now commercialized by ApDia)(Waiswa et al., 2009). This ELISA test has a sensitivity of 86.7% and specificity of 94.7% (Dorny et al., 2004) and was used in the current study.

In a study in 2005 in Kamuli and Kaliro district, Waiswa et al.,(2009) reported a B158/B60 Ag ELISA prevalence of 8.5% (95% CI 6–11%) (n=513 for the two districts). The drivers for the fluctuation in the prevalence rates between the 2005 study and the current study is not yet known. However, we may hypothesize this marked reduction in prevalence between the two studies could be attributed to the ongoing improvements in the pig husbandry practices, increased latrine coverage across Kamuli or adoption of MDA programs targeting neglected tropical diseases (NTDs). This finding is supported by a report of Uganda's Ministry of Health documenting that MDA programs are annually conducted in Kamuli and Hoima districts using praziquantel to control schistosomiasis (bilharzia) (MoH, 2010). Praziquantel is also effective against taeniasis in humans. This may have reduced the number of tapeworm carriers, consequently reducing PCC incidence.

In 2005, Waiswa et al.(2009) reported that free ranging management system was the most common husbandry practice in Kamuli. This present study shows that the shift to tethering with supplementary feeding may have reduced the opportunities for pigs to get exposed to parasite infective stages. Nsadha *et al.,* (2010)reported rampant open defecation by farmers in the fields due to long distances to the toilets. In contrast, the current study indicates that most households (92.3%) in Kamuli district had a pit latrine, reducing the potential for transmission events. However, further studies are required to understand barriers to toilet use since the current study showed that only 42.3% of toilets had a complete wall and door, a sign of ease of use due to privacy.

Additionally, there could be differential latrine coverage across different geographical locations within the districts, especially along the water bodies like Lake Albert in Hoima district and along River Nile in Kamuli district. These places are prone to flooding and toilet construction may be challenging. Nsadha et al. (2010) noted around 25% of households lacked toilets in the large Lake Kyoga region (includes Kamuli district) and that those available were used intermittently. Seasonal confinement of pigs as observed in the current study may mean that pigs are occasionally exposed to parasite infective materials, an observation also reported by Assana et al. (2010) in Cameroon and Secka et al. (2010) in the Gambia and Senegal.

Risk factors for porcine cysticercosis

District was a significant predictor of PCC seropositivity in the univariable analysis. The prevalence of open defecation may differ between districts, possibly because Hoima district has large areas covered with dense vegetation that may suggest "adequate privacy" for open defecation. It is less so in Kamuli district. Similar observations have been made in Nigeria (Abubakar, 2018) and in Tanzania (Sara & Graham, 2014). However, this observation needs verification by anthropological studies to explain community behaviour and its drivers on toilet use and open defecation, as Thompson (2017) did.

This study identified an association between seropositivity and knowledge that pigs can get infected by eating dirty feed. In the causal diagram, we hypothesized that having knowledge regarding. *solium* transmission would have a protective effect on seropositivity. Still, the variable appears to be a risk factor in our analysis. This relationship's theoretical basis is unclear and may need further investigation, although we acknowledge that the association may be a statistical artifact. Other studies have found that knowledge of the transmission cycle was associated with reduced risk of the disease but not knowledge on the risk of feeding contaminated feeds (Kunguet al., 2017). These findings may mean knowledge does not always translate to change in practice, similar to observation by Sarti and Rajshekhar (2003) and Gabriël et al. (2017). Although pig farmers may know the health risk of feeding pigs dirty or contaminated feeds, resource constraints and the reliance on crop residues and swill as feed for pigs may mean infective materials are introduced to the pigs even when they are confined or tethered. Additionally, some changes in practices need to be accompanied by capital investments like the construction of pig pens and toilets, which may lead to a lack of change in practice even after knowledge uptake in regions with limited resources (Elsa Sarti & Rajshekhar, 2003). Therefore, innovative ways of supporting change of practice may be necessary, for example, nudges (reminders), incentives and dis-incentives to reinforce good practices and deter negative practices, and infrastructural investments to support change in practices.

Prevalence and infection intensity of gastrointestinal parasites

Several studies have investigated the prevalence and intensity of pig gastrointestinal helminths in Uganda, but none has been done in Hoima district. In the current study, the overall prevalence of infection with the GI parasites was 91.8% (95% CI 88.9 – 94.9%) for the two districts. Kamuli district had 93.0 (89.5 – 97.0, 95% CI) and Hoima district 90.5 (86.1 – 95.0, 95% CI). The most prevalent infection strongyles at 79.0% (74.3 – 83.6). Similar infection levels have been reported in different regions of Uganda(Nissen et al. 2011; Lagu et al. 2017;Waiswa et al. 2007). Roesel et al. (2017) reported similar trends (61.4%, 58.2 – 64.4; 95% CI), with strongyles being the most prevalent infection. Similar trends of parasitic infections have been reported in the neighbouring countries by Obonyo et al. (2012) and Nganga et al. (2008) in Kenya and Kabululu et al. (2015) in Tanzania. Incidentally, one pig was found to be infected with *Moniezia spp*., which is known to be a ruminant parasite but has been previously found in pigs in Peru (Gómez-Puerta et al., 2008). The pig could have been infected through ingestion of the oribatid mite carrying infective cysticercoids as it scavenges. Oribatid mites which occur across the world are the known intermediate hosts for *Moniezia* spp.(Barriga, 1997).

The intensity of infections was also high, as indicated by the high EPG counts with strongyles having the highest EPG (616.1). Nissen et al., (2011) in a study in Kabale district, Uganda, reported similar mean EPG for strongyles of 964 and high mean EPG for *Ascaris* spp. (4673) and *Trichuris* *suis* (264) than the current study. Similar intensities of parasite infections have also been reported by Lagu et al. (2017) and Waiswa et al. (2007). There was also a high OPG mean for coccidia (2042.2). Internal pig parasites are of high importance to farmers due to the resultant reduction in performance and financial losses due to their infection. Coccidiosis, particularly *Isospora suis*, cause diarrhea and reduced growth in piglets leading to financial losses and an increase in the cost of managing the infections (Ózsvári, 2018). Although deworming is widely practiced by farmers as observed in this study (97.3% in Kamuli and 98.5% in Hoima deworm pigs), the frequency may be low and the type of anthelmintic drug wrong for the existing infections leading to persistence in the infections. This is because farmers overly relied on one type of anthelmintic overtime, and they are not consistent with the deworming intervals. Forty-eight per cent of the farmers said that they dewormed the pigs after 3-month intervals, mostly using Levamisole or Albendazole. However, it has also been noted that farmers rely on the veterinary officer advice on what drug to administer.

Opportunity for integration of porcine cysticercosis and gastrointestinal nematodes control

The high proportion of co-infection of pigs with GI parasites and PCC (57.4%) is of significance to report in the current study. It presents an opportunity to use integrated approaches to control both parasites. Farmers in Uganda recognize infection with worms as a major constraint to pig production (Dione et al. 2014), but not so for PCC. Farmers have also been found to extensively practice deworming of pigs to control internal parasites.We must capitalise on the' added value' of control options as we investigate acceptable and sustainable interventions to control *T. solium* cysticercosis.In the current study, 95% of farmers dewormed pigs mainly using albendazole, findings similar to results by Dione et al. (2014), who reported 93% dewormed pigs mostly with Ivermectin, 85% of farmers used Albendazole (Kungu et al., 2017b). The anthelmintic drugs:

Albendazole, Levamisole and Ivermectin reported to be commonly used by farmers have been found not to be effective against PCC (Mkupasiet al., 2013a; Mkupasiet al., 2013b). Promotion of regular deworming using appropriate anthelmintic and including oxfendazole as part of the deworming regime can help control GI parasite infections while at the same time controlling PCC infections.Administration of oxfendazole at 30mg per kg effectively kills *T. solium* cysts and has been demonstrated to also control *A. suum, Oesophagostomum* spp.*, T. suis* and *Metastrongylus* spp. in pigs (Alvarez et al., 2013; Mkupasiet al., 2013). However, the cost-benefit of using oxfendazole to target GI worms while controlling PCC needs to be investigated.

Limitation of the study

The study had the following limitations:

1. The current study was embedded within the Uganda Pig Genetics project that was designed as a longitudinal study. The implementation of a cross-sectional study using the same study subjects may have biased the risk factor analysis since they had been in touch with research teams during data collection and may have improved their knowledge, perception and even practices on pig husbandry.
2. We used ApDia ELISA kits to detect *Taenia solium* circulating antigens in pig serum, but there is known cross reactivity with *Taenia hydatigena* antigens that may raise false positives. We had planned to carry out carcass dissection, which is the 'gold standard' technique on all the seropositive pigs but this was not possible due to the COVID-19 pandemic, which prevented the team from returning for farm visits to procure the positive pigs before they were sold for slaughter.

3. For estimation of GI parasite infections, we did not reach the estimated sample size since some of the targeted farmers had ineligible or had sold their pigs. However, the results are robust since the prevalence of the GI parasites was high.

Conclusion

1. This study provides data on the current epidemiological status of PCC and pig GI parasites in Kamuli and Hoima districts, Uganda. The findings demonstrate that *T. Solium* cysticercosis in pigs is more prevalent in Hoima district than in Kamuli district, which is lower than previously reported. Knowledge that pigs can get infected by eating dirt feeds was a significant predictor for *T. solium cysticercosis* seropositivity at the household level.
2. The prevalence of infection with gastrointestinal parasites is high and similar across the two districts. There is also a high likelihood of pigs being infected with both PCC and GI parasites. Since deworming is practiced by many farmers in the study districts, the high rate of co-infection presents an opportunity for integrated control using an anthelmintic capable of eliminating both *T. solium cysts* and other pig worms.
3. Further studies are required to identify and test the feasibility, cost benefit analysis and acceptability of using such anthelmintics (including oxfendazole).

CHAPTER FIVE

STAKEHOLDERS' KNOWLEDGE, ATTITUDES, PERCEPTIONS AND THE ACCEPTABILITY OF *TAENIA SOLIUM* CONTROL STRATEGIES IN KAMULI AND HOIMA DISTRICTS, UGANDA

ABSTRACT

Taenia (T.) solium is a zoonotic parasite causing three diseases: - taeniasis and cysticercosis in humans and porcine cysticercosis in pigs. Although, the transmission of the parasite can be easily interrupted at six points along the life cycle, the contextual factors which may influence the adoption of these control strategies in Uganda remain unclear. This study assessed the stakeholders' knowledge, attitudes perceptions and acceptability relating to six control strategies for *T. solium* infections in Kamuli and Hoima districts, Uganda. A total of 22 focus group discussions (FGD) were conducted with pig farmers, community leaders, pig/pork traders, animal health assistants and human health assistants. In addition, nine key informant interviews (KII)were held with senior officials in the ministries of agriculture and health including district veterinary officers, and other relevant agencies at the district level.

The results showed differential, limited and fragmented knowledge on *T. solium* infections among the stakeholders. Pig farmers, community leaders and pig/pork traders had almost no knowledge and were often confused regarding the differences existing between *T. solium* and other gastro-intestinal infections in pigs and humans. Pig confinement, pit latrine construction, coverage, maintenance and sustained use were influenced by cultural, socio-economic, and physical/ environmental factors of study population and area. Mass drug administration for school children and adults, vaccination of pigs with TSOL18 vaccine plus treatment with oxfendazole and health education implemented at community level were widely acceptable to the local stakeholders and

could be successful if the prices for the vaccine and dewormer were subsidized. Proper sensitization programmes and health education interventions should target all, but with material appropriately focused to suit the stakeholder's category. Reminders or nudges may be needed to ensure that any increase in knowledge translates to changes in practice.

5.1 Introduction

Local demand for pork has driven growth in pig production in Uganda significantly since the 1990s (MAAIF and UBOS, 2008;Ouma et al., 2015). Around 70% of pork produced in Uganda is consumed domestically at roadside butcheries and eateries (commonly known as pork joints (Roesel et al., 2019). The majority of pigs slaughtered and consumed in these joints are raised by small holder farmers who are resource constrained and rear pigs extensively with little investment in housing and feeding (Tatwangire, 2014). Many of the pigs are either tethered or intermittently housed during the year depending on the season. They are fed mostly on crop residues (Dione et al., 2014). The rural areas in Uganda are also characterized by low coverage and under-use of sanitation facilities (Ministry of Water and Environment, 2018) creating a suitable environment for transmission of *T. solium*.

T. solium is a zoonotic parasite causing three diseases: - taeniasis and cysticercosis in humans and porcine cysticercosis in pigs. Taeniasis is the presence of adult tapeworms in the intestines of humans and results from consumption of undercooked pork containing viable cysts. In pigs, the ingestion of the tapeworm eggs from the environment leads to development of cysticerci in the striated muscles, a condition known as porcine cysticercosis (PCC). Humans can also get cysticercosis after ingestion of the tapeworm eggs, shed by themselves or other humans. If the cysticerci lodge in the central nervous system, it leads to neurocysticercosis (NCC), a disease of serious health and social burden (Carabin et al., 2011; Del Brutto & García, 2014; García et al., 2003).

The transmission of the parasite can be interrupted at six points along the life cycle which have been simplified in the *"Lets break the pork tapeworm cycle*" poster (ILRI & Medical Research Council, 2005). These include:- 1) use of toilets, 2)washing hands, fruits and vegetables, 3) deworming children and adults regularly, 4) pig confinement, 5) meat inspection and 6) proper cooking of pork (ILRI & Medical Research Council, 2005). In order to reduce the burden of NCC, three control strategies have also been proposed and tested for effectiveness at community level in different endemic settings including; mass drug administration (MDA) of praziquantel to control taeniasis in humans (Carabin & Traoré, 2014), vaccination of pigs with TSOL18 vaccine combined with treatment using oxfendazole (Lightowlers & Donadeu, 2017) and health education (Lightowlers, 2013; Thomas, 2015). The success of the different control strategies may be influenced by the contextual factors operating in the target area which may include socio-economic, cultural and geographical and environment factors (Ngwili, Johnson, et al., 2021).

In Uganda, the socio-economic, cultural and other factors that may influence the adoption of the six control strategies aimed at disrupting the transmission of the parasite have not been studied. The acceptability of the proposed community-based interventions has also not been studied. This study therefore, aimed at: - i) determining the knowledge, attitude and perceptions of different stakeholders on the control of *T. solium* and ii) assessing the acceptability of the proposed *T. solium* control strategies among different stakeholders.

5.2 Materials and methods

5.2.1 Study area

The study was conducted between March and April 2021 in Kamuli and Hoima districts, Uganda. These districts have high numbers of pig rearing households and high demand for pig meat and pig products (Ouma et al., 2017). The districts of Kamuli and Hoima were chosen as ideal because they host the Uganda pig genetics project (UPG) led by the International Livestock Research Institute (ILRI), and their pig value chain has been previously well characterised (Asiimwe et al., 2015; Ouma et al., 2015). In each district community participants were drawn from villages within 3 sub-counties out of 14 and 5 subcounties in Kamuli and Hoima district, respectively. However, the ministry official participants were drawn from across the districts.

5.2.2 Study design and selection of stakeholders

A community-based, qualitative study design was used. Focus group discussions (FGDs) comprising of 8 – 10 participants and key informant interviews (KII) were used to collect qualitative data. Different stakeholder categories play different roles in *T. solium* control and therefore the FGDs were organized by stakeholder category. The FGDs and KIIs were conducted as per the identified stakeholder categories shown in Table 5.1. To identify the stakeholders, a preliminary list was generated based on pig value chain scoping visit conducted in 2014 (Ouma & Dione, 2014). The researcher then visited the two sites (Kamuli and Hoima districts) to identify the specific stakeholders, explain the project and check their availability to participate. For the pig farmer stakeholder category, separate FGDs were held for men and women. Ten community leaders from each district were randomly selected from a list of 30 village leaders from villages which participated in the cross-sectional study in 2019 (See section 4.2.2). For farmers, the participants were selected randomly from a list of pig farmers who participated in the cross-sectional study in 2019 (See section 4.2.2). The random function in excel was used for the randomization. A maximum of 10 participants per category were invited for the FGD to ensure social distancing as per COVID-19 pandemic protocols.

Table 5. 1: Stakeholder categories and their description.

Stakeholder category	**Description/Target person or group**	**Relevance to *T. solium* control**	**Method used for data collection**
Pig farmers	Pig farmers selected randomly from a list of pig farmers from 30 villages	They are responsible for control of the parasite at the intermediate and final host stage by practising proper hygiene and good pig husbandry.	FGD
Community leaders (LC1)	Selected randomly from villages across 3 sub-counties	They are village leaders and are the link between the national government administration and the communities. They are involved in enforcing latrine use and other by-laws within the village.	FGD
Animal Health Assistants	Purposively invited through the District Veterinary Officer (DVO) and were drawn from the different sub-counties in the district.	They oversee meat inspection and promotion of good animal husbandry at sub-county level.	FGD
Human Health Assistants	Purposively selected and invited through the District Health Officer (DHO) and were drawn from the different sub-counties in the district.	They oversee human health activities in a sub-county and act as the heads of level 3 health facilities (the government health facility at the sub-county level	FGD
Pig/pork traders	Selected by snowballing from different sub-counties within the district starting from the district	They buy pigs from farmers and operate butcheries and pork joints at the sub-country level where they sell raw and ready-to-eat pork.	FGD

	headquarters. Three traders were picked from each sub-county.		
District Veterinary Officers (DVO)	One officer from each district of study. Hoima district was recently subdivided in to 2 and therefore 2 DVOs were included.	They oversee veterinary and animal production in the district including meat inspection.	KII
District health officers (DHO)	One officer from each district of study (1 from Kamuli and 2 from Hoima district).	They oversee human health activities in the district including promotion of community hygiene.	KII
Private company (Devenish Nutrition in Hoima)	Outreach officer	The private company is involved in training of farmers and sale of inputs to pig farmers.	KII
Catholic NGO (HOCADEO-Hoima)	Veterinary extension officer	They are involved in promotion of pig husbandry and general household hygiene including toilet construction	KII
Neglected Tropical disease focal person under vector control division Ministry of Health - Kamuli	One official in Kamuli	They oversee mass drug administration campaigns in the district to control schistosomiasis. Praziquantel which is the drug of choice also treats taeniasis.	KII
National Animal Genetic Resources centre and Databank (NAGRIC & DB)	Head of community breeding programme	They are involved in extension work promoting improved pig husbandry.	KII
Iowa State University Uganda programme	The head of programme in Kamuli field office	They are involved in extension work promoting improved pig husbandry as well as household nutrition.	KII

5.2.3 Data collection and management

A FGD and KII checklist was developed along the six points along which the transmission *T. solium* can be interrupted in its life cycle as listed earlier in section 5.1and outlined in Figure5.1. The FGD and KII guides were pretested in the peri urban areas of Kampala with the different stakeholder categories. Changes were reviewed by the study team and adjustments made to the guides.

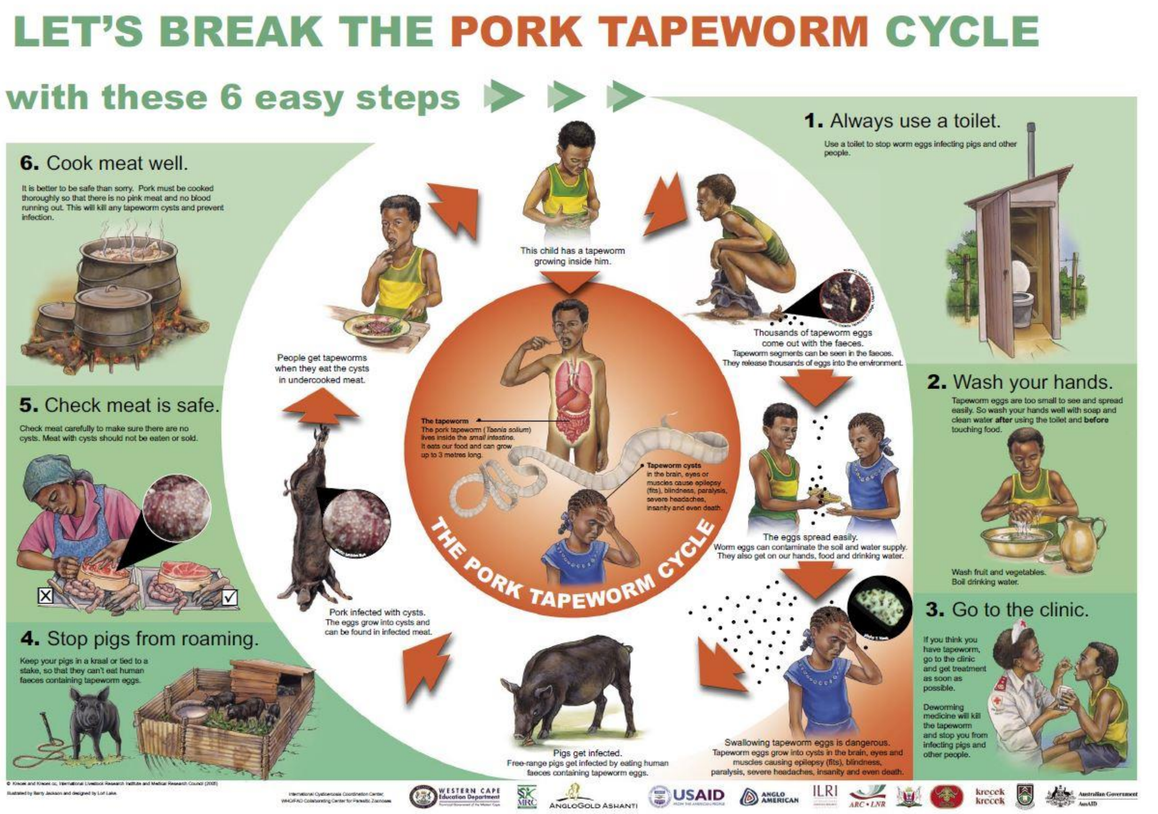

Figure 5. 1: The "let's break the pork tapeworm life cycle" poster: Source **(ILRI & Medical Research Council, 2005)**

Data were collected by 2 facilitators who were fluent in Runyoro/Runyankole (local language in Hoima) and Lusoga (local language in Kamuli), one acting as a moderator and the other one a note taker. The FGDs with the ministry officials were conducted using both English and the local language understood by the participants. The KIIs were conducted exclusively in English by the lead researcher. All the FGDs and KIIs were audio-recorded using an electronic recorder and notes were taken. The audio files were transcribed verbatim into English by transcribers fluent in Runyoro/Runyankole and Lusoga languages. The typed scripts were verified through listening to audio files and comparing with the notes. The data were coded into themes developed along the six control points in NVivo version 12 (QSR International Pty Ltd, 2010). A coding frame was first developed using the prior knowledge on the control of *T. solium* and then data coded into the respective codes or themes. The data was analyzed using the deductive content analysis(Elo & Kyngäs, 2008).

5.2.4 Ethical statement

Ethical clearance was obtained from International Livestock Research Institute's (ILRI) Institutional Research Ethics Committee (ILRI-IREC), reference number ILRI-IREC 2019-20 with extension reference number ILRI-IREC2019-20/2, respectively. Since the study was conducted in Uganda, approval was also obtained for the Research and Ethics Committee at the College of Veterinary Medicine, Animal Resources and Biosecurity, Makerere University (reference. SBLS/HDRC/19/008) and a research permit obtained from the Uganda National Council for Science and Technology (reference A606). Before the start of the meetings consent to participate and allow recording of the discussion was sought from both the FGD and KII participants and all of them signed an informed consent form.

5.3Results

The results section is divided into sections along the six points at where the transmission of *T. solium* infections can be interrupted.

5.3.1 Demographic characteristics

A total of 210 discussants participated in twenty-two FGDs comprising twelve FGDs with pig farmers, two FGDs each with animal health assistants, human health assistants, community leaders, pig/pork traders and people affected by *T. solium* infections. For the pig farmers, six FGDs were conducted in each district and one FGD in each district for the other stakeholder categories. A further, nine KIIs were conducted in both Kamuli and Hoima districts, three with DVOs, two with DHOs, one with a Veterinary Officer working for local catholic relief organization in Hoima, one each with a local private company in Hoima, the neglected tropical disease focal person under the vector control division of ministry of health in Kamuli, the head of community breeding programme for NAGRIC & DB and the director of Iowa State University Uganda programme. Two FGDs were also conducted with leaders of local pig farmer associations in Kamuli and Hoima districts. A full list of FGDs and KIIs can be found in Table 5.1. In total 57 men and 59 women pig farmers attended the FGDs in both Kamuli and Hoima districts. The demographic characteristics of the participants are presented in (Table 5.2).

Table 5. 2: Demographic characteristics.

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

5.3.2 Knowledge and awareness on *Taenia solium* infections

During the FGDs with the various stakeholders, it was established that there were different levels of knowledge on *T. solium* and its control. Among the pig farmers there was generally poor knowledge and awareness about the pork tapeworm. Majority of the farmers thought that the pork tapeworm is a type of worm infection that is found in the stomach or intestines of pigs. Some of the farmers described the worm as being whitish in colour. There were some participants, who however, were fully aware and had also seen the tapeworms in faeces of children.

"The tape worm is found in the stomach [of pigs]; it affects the intestines of the pigs leading to stunted growth. The tape worm is white in color and lives around the intestines"- F10, women FGD, Hoima District.

"It manifests in humans. When defecating you can easily identify that a child has tape worm after he has defecated" – P3, Men FGD, Kamuli District

Similarly, pig/pork traders and community leaders in both districts had poor knowledge on the pork tapeworm manifestation in pigs, although the majority agreed that pigs get infected when they roam around and feed on dirt including soil.

"Tape worms are small, and they affect pigs if they are not treated" – R4 pig trader, Hoima district

"The tape worm we are talking about is white in color and it looks like a round tape worm, and it is elastic. When it is in an animal especially the pigs, it makes it stunted, with swollen stomach".
- P1, Community leaders, Kamuli District

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

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

"if an infected person defecates in the open environment, the feaces can be taken by running water to water sources and the egg if that water is taken unboiled, the human being gets the tape worms" - R9, men FGD, Hoima District.

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

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

"The pigs are the intermediate host. Human beings are the final hosts" – R5, Animal health assistants, Hoima District.

"Human beings get infected by tape worms through eating unwashed raw fruits like mangoes and uncooked sweet potatoes. If a human being steps on the feaces of an infected person with the eggs

of the tape worm, they also get infected" – R6, community leaders, Hoima District

5.3.3 Latrine construction, coverage, and use

Discussants in the farmers' stakeholder category estimated the pit latrine coverage in their villages to be over half. However, the majority agreed that less than half were in bad condition – lacking complete walls, a door or roof. The estimate by the human health assistants who were the promoters of community hygiene was not different. In both districts, the human health assistants estimated the coverage to be slightly above half with less than half having permanent structures. The discussants in the community leaders' category from both districts gave the highest estimate of latrine coverage. The human health assistants noted that in both Kamuli and Hoima districts, the sub-counties along flood-prone areas like the banks of river Nile in Kamuli District and the shores of Lake Albert in Hoima District had low latrine coverage due to occasional flooding.

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

"2/10 households have permanent latrines, and 5/10 households have semi-permanent latrines while 3/10 have latrines without shelters…. Some households dig the pit and put the slab and do not put the shelter" – R5, Community leaders FGD, Hoima District.

"Most of them are made of grass, mud, poles and reeds" – R1, Human Health Assistants, Hoima District.

"They are permanent and temporary, and these are made of cement, bricks, iron sheets, gravel, sand, tiles and pipes" – R6, Human health assistants, Hoima District.

Several barriers to pit latrine construction were identified. Many participants cited lack of resources to buy building materials as the main challenge in latrine construction. Other challenges included lack of construction equipment like hoes and spades, lack of space to construct the latrine, weak soils, rocky areas which made digging hard, high-water table especially along the flood plains, traditional norms, and customs that inhibited older generations from constructing latrines. Also, ignorance on the importance of having a latrine was cited by the participants. In Hoima pig farmer discussants noted that they had formed a group to help them mobilize resources for buying materials, digging and constructing pit latrines as a group.

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

"Some soils are weak making them break so fast. The costs of constructing Latrines are high. And some soils are rocky making it difficult to dig pits" – R5, Human Health Assistants, Hoima District.

For the semi-permanent latrines made using non-commercial materials, the role of men was to dig the pit, cut logs and build the latrine. On the other hand, women helped with light jobs during construction like cutting grass for thatching and fetching water. In terms of maintenance, most of the farmers agreed that women cleaned the latrines using brooms and ashes, trained the children on pit latrine use and enforced latrine use. On the other hand, it was noted that in most cases the household head funded construction of permanent latrines and paid for the mason.

At community level, enforcement of pit latrine construction and promotion of household hygiene was reported to be carried out by the community leaders and village health teams (VHTs), the latter is recruited by the Ministry of Health. Overall, this role was identified by discussants in the farmers, community leaders, traders, human and animal health assistants' stakeholder category. This was also supported by the KIIs with the district health officers in both districts.

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

Barriers to Latrine use

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

i). No pit latrines: Those without latrines were reported to use their neigbours' latrines or use a polythene bag and later throw especially those in urban areas or go with a hoe and dig a hole in the farm and defecate in it or defecate in banana, sugarcane plantation or in nearby bushes.

ii). Age: Children below 5 years and the elderly did not use pit latrines as identified by majority of farmers and community leaders. The children defecate around the latrine and the faeces were thrown in the latrine or in the garden. The elderly dug a hole in the garden and defecate or defecate in the bushes or sugarcane plantations.

iii). Poorly constructed latrines with weak slabs or openings which made people fear falling into the pit, as identified by some of farmers and the community leaders.

iv). Poor lighting in the latrines prevented their use at night out of fearof rodents and snakes

v). Poor state of hygiene and crowding in public latrines during public functions or market days

vi). Smelly latrines

vii). Wrong intentions for construction of latrines where some construct latrines to be seen by the enforcement officers and avoid punishment. Additionally, others constructed the wall and roof without the pit just to trick the enforcement officers.

viii). Cost minimization led to fear of using the toilet to avoid it getting full and having to construct another one.

ix). Drunkards and mentally disabled people were reported not to use latrines

x). Beliefs such as

a. Women should not use latrines otherwise they will never bear children,
b. Pregnant women should not use latrines.
c. Children feaces should not be thrown in latrines as they are not harmful and will just decompose.

5.3.4 Hand washing and personal hygiene

Majority of the discussants in the farmers and community leaders' stakeholder category noted that hand washing facilities were available near the latrine or in the compounds, usually in form of a small jerry-can ('tippy tap') and in some cases, there was soap. It was also pointed out that this had become more common and adopted due the ongoing campaign occasioned by the current COVID-19 pandemic.

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

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

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

5.3.5Deworming of children and other household members

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

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

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

5.3.6 Confinement of pigs

Pig farmers appeared to have knowledge that housing pigs has benefits including prevention of diseases like African swine fever (ASF) and worm infections and avoiding conflict with neighbours if the pigs roam into their farms. However, most of the farmers and community leaders noted that there were free roaming pigs in their respective villages. Some farmers also confined pigs during the rainy season and let them roam during the dry season. The reasons for not housing pigs included - i) lack of resources to construct pig pens ii) poorly constructed pig pens which are easily destroyed by the pigs iii) Some farmers had farms which were far from their residencies where the pigs are kept and this forced them to leave the pigs to roam and look for feed as they go to work on the farms, iv) pig feeds were also reported to be expensive and therefore farmers preferred to leave the pigs to scavenge for feed. Additionally, some farmers believed that free roaming pigs grew faster as compared to confined pigs v) Lastly, pig rearing responsibility (feeding the pigs) was not prioritized in the households; hence the pigs were left to scavenge for feed.

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

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

5.3.7Meat inspection

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

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

The traders relied on the government meat inspectors who at times failed to reach their slaughter place. In that case they would go ahead and sell uninspected pork. But it was reported by one of the traders that while local consumers do not demand to see a meat inspection stamp, consumers from Kampala do. The discussants also noted that if the meat inspectors arrived late, they inspected the meat while it is at the butchery being sold. In the animal health assistants/ meat inspectors' stakeholder category, many of the discussants noted that there was lack of centralized slaughter facilities which left them unprotected from disgruntled butchers if they condemned carcasses during inspection. Carcasses were rarely condemned, in most cases they did conditional passing, where they passed the meat but instructed that it be properly cooked. Partial condemnation is more common, and it involved the condemnation of the infected part only. Political interference (in terms of challenging the enforcement of the laws by protecting their constituents) was cited as the major challenge to enforcement of meat inspection. The participants in the KIIs with DVOs noted that meat inspection is covered under the public health act, Uganda but enforcement was constrained by lack of resources for transport to slaughter places, understaffing, lack of centralized slaughter facility and political interference.

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

5.3.8 Pork preparation

Majority of farmers identified butcheries and pork joints as being the main sources of raw and cooked (ready to eat) pork. In some rare circumstances people were reported to have bought a pig, slaughtered and shared the pork especially during festivities. It was also reported that women were mainly responsible for preparing pork at home for consumption by household members.

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

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

i. Acceptability of community-level *T. solium* control strategies

(a) Mass drug administration

The MDAs were targeted at sub-counties with high prevalence of soil transmitted helminths (STHs) infections as reported by majority of discussants in the human health assistants' stakeholder category and the district health officers. It was also reported by the same stakeholder categories that albendazole or mebendazole was commonly used and praziquantel when the target was schistosomiasis. Many of the pig farmers discussants noted that they were always motivated to take children for deworming to prevent them from getting sick, having stunted growth and save money from sickness because the drugs were provided for free. The farmers' stakeholder category noted that MDAs were well promoted through sensitization campaigns carried out by the community leaders and VHTs and through mass media like radios. These observations were supported by the discussants in the human health assistants' stakeholder category, 2 KIIs with district health officials and 1 KII with the NTD focal person for Kamuli District. However, it was noted that there were always limited supply of drugs and the MDA programs were dependent on donor funding. The discussants in the human health assistants' category noted that there was need to expand the programs to adult populations who were the main consumers of pork to target the pork tapeworm and other worms.

(b) Vaccination and administration of oxfendazole in pigs

Majority of the discussants among the pig farmers' and pig trader stakeholder category had good awareness on the importance of deworming pigs to control internal parasites, however, they did not know that there was a vaccine and dewormer targeting *T. solium* infection in pigs.

"Deworming increases incomes due to improved pig health. Pigs become stunted due to worms if you don't deworm" – R5, Men FGD, Hoima District.

The discussants also noted that the motivation to adopt vaccination and treatment of pigs would be if it will make the pigs grow fast and fetch good prices. Sensitization on the vaccine and dewormer, the availability of the vaccine and dewormer in local agro-shops in small packages and at reduced prices was also reported to important. Additionally, the fact that the vaccination and treatment of the pigs will prevent infection in people was also a motivating factor (pig farmer FGDs, community leaders' FGDs and pig trader FGDs). Discussants in the animal health assistants' stakeholder category and some in the human health assistants' stakeholder category noted that packaging of vaccine and dewormer in small quantities, provision of the drugs for free, sensitization and incentives to those who adopt the practices will support uptake.

"There at times when we buy pigs which have lost weight so if vaccinated and dewormed, pigs can put on weight and weigh many kilograms that can motivate" – R7, Pig trader FGD, Hoima District.

"If the drug comes when is cheaper or at subsidized price, we can buy it because we don't want our pigs to get these worms and even infect us human being" – P1, Men FGD, Kamuli District.

The discussants noted that they were willing to buy the dewormer because it will help control many worm infections in pigs, however the issue of selling substandard drugs/ anthelmintics was raised.

"The problem we have these drugs come on market and tell us its good but afterwards we see fake drugs which doesn't even work. It is only the first people to buy who benefits before the drug is faked"– P4, Women FGD, Kamuli District.

Majority of the discussants in the animal health assistants' category reported that the government should launch the vaccination campaigns for free or subsidize the vaccine because most farmers did not identify *T. solium* infections in pigs as a big challenge. They also observed that these programmes would benefit more farmers who reared their pigs through free range system.

(c) Health education

Majority of the discussants in all the stakeholder categories noted that it is important to carry out health education campaigns to sensitize people and improve their awareness on *T. solium* infections, its consequences and how it could be controlled. Particularly, some of the farmers and traders noted that they welcomed the idea of sensitization because it would make their pig farming enterprise profitable.

"Health education will create awareness, sensitize and mobilize people who don't know the truth about the tapeworm and its consequences" – R4, Animal health assistants FGD, Hoima District.

Discussants in the animal health assistants' and human health assistants' FGDs identified the following modes of disseminating information :- i) use of posters in public places with information on the tapeworm in local language to sensitize farmers, ii) conduct training in schools to sensitize school going children on worm infections iii) use of radio where messages on the control of the tapeworm can be delivered during popular radio shows which are listened by many people and iv) work with local community leaders and VHTs to mobilize and sensitize people. Many of the pig farmers identified the use of local community leaders, VHTs and the use of radio to create awareness about *T. solium* infections as the most appropriate channels. It was also noted that traders, butchers and pork joint operators could sensitize their customers on the need to eat well cooked or roasted pork.

5.4 Discussion

Among the various type of stakeholders targeted, pig farmers had the lowest level of knowledge specifically on *T. solium* infections. Similar findings were reported in Northern Uganda (Alarakol et al., 2020). There was confusion of the pork tapeworm with other pig gastrointestinal helminths, results similar to those reported in Eastern Zambia (Thys et al., 2016). This could be because farmers could easily identify infection of pigs with worms through physical symptoms such as stunted growth, reduced weight gain, emaciation and identification of the nematodes in pig faeces. The pig gastrointestinal parasites were prevalent in Uganda and have been extensively reported in various locations including Kamuli and Hoima district (Nissen et al., 2011; Roesel et al., 2017;Ngwiliet al., 2021).

A limited number of participants were aware about tapeworm infection in children but not in adults. Taeniasis could be due to infections with either *T. solium* or *T. saginata* both of which have not been well studied in human populations in Uganda, except in one study which reported a prevalence of 0.7% for taeniasis among school children in Kampala (Kabatereine et al., 1997). Since the participants could not clearly describe the worms seen in the faeces , these could be other intestinal helminths which have been reported in school going children in Uganda (Adriko et al., 2018; Kabatereine et al., 1997). Knowledge on the tapeworm was highest among human and animal health professionals albeit with confusion on how the infection with *T. solium* leads to neurocysticercosis/epilepsy. Similar findings were reported in Tanzania among veterinary extension officers and medical health professionals (Ertel et al., 2017b).

The infection of pigs with *T. solium* cysticercosis does not produce any identifiable clinical signs and may persist unnoticed in pigs. Kungu et al. (2017) using a household survey reported high knowledge performance score of farmers on *T. solium* infections transmission in Uganda which is in contrast with findings of the current study. Low knowledge levels on *T. solium* transmission in the general population have been reported in Tanzania (Maridadi et al., 2011). One limitation of these studies is that they used a ‘yes/no’ knowledge question implanted in a household survey which may have not brought out the underlying true knowledge levels. Low awareness and knowledge on *T. solium* infections and transmission reported in this study may be a barrier to adoption of practices aimed at breaking the transmission cycle and reducing the incidence and prevalence of the infections.

Although, there was high pit latrine coverage in the study districts, many of the toilets were poorly constructed. The national latrine coverage in Uganda stood at 79% in 2018 with 3 out of 10 households lacking a latrine (Ministry of Health, 2021; UNICEF, 2021). The high cost of toilet construction may have led to the construction of latrines which were hard to use due to weak slabs or slabs with large spaces between the poles which may collapse, have incomplete walls and roof. Latrine construction was also affected by rocky, loose or sandy soils and high-water table in areas along the flood plains which made it hard to build pit latrines. Similar challenges due to soil formations were reported in Ghana (Nunbogu et al., 2019).Günther et al. (2016) noted that lack of liquidity was the major barrier to investment in latrine construction in Uganda. The cost of constructing a ventilated pit latrine with a plastered brick structure was estimated at USD 760 in peri-urban Kampala (Lüthi et al., 2013).The median monthly wage for rural population in Uganda was estimated at UGX 120,000 approx. USD 33 (at USD 1= UGX 3,600)and UGX 220,000 approx. USD 61 for urban population in 2016(Uganda Bureau of Statistics (UBOS), 2018). This may mean that majority of households may struggle or may be unable to construct a modern toilet given the estimated cost with this income level.

During latrine construction, men and women played differential roles with men taking up the more physical activities like digging the pit and women supported construction by fetching water and thatching materials. Nunbogu et al. (2019) made similar observations in Ghana. Additionally, another important aspect in latrine use was maintenance of cleanliness and latrine use enforcement which was done by women at the household level. Dissemination of information and enforcement of latrine construction and use without capital investments may not be sufficient to increase coverage and sustained use. Further, gendered roles on latrine construction use and maintenance should be considered when designing interventions to increase pit latrine coverage and use.

Although, significant latrine coverage was reported in the current study as was also estimated by the government of Uganda at 79% (Ministry of Health, 2021), open defecation, which is a risk factor for *T. solium* cysticercosis and other infections, was reportedly still practised especially by the elderly, children and in some instances other household members. Similar findings were reported in a systematic literature review on latrine coverage and use by Garn et al. (2017) who noted open defecation even among households with latrines. Free roaming pigs could easily access and eat faeces as they scavenge, or eggs can be introduced to the pigs through feeds such as sweet potato vines and tubers perpetuating the transmission of the parasite. In-pen infection has been reported in Tanzania (Braae et al., 2015; Komba et al., 2013b).

Additionally, open defection in gardens can contaminate fruits, vegetables and cassava or sweet potato tubers presenting a risk for neurocysticercosis to household members. Some barriers to latrine use and which promote open defecation included design of the latrine which does not guaranteed privacy and ease of use, poor maintenance and lack of cleaning resulting to dirt latrines and lack of clear paths and lighting inside the latrines. These findings are consistent with findings by Kwiringira et al. (2014) who reported open defecation was practised in the slums of Kampala, Uganda and in Lodwar town, Kenya (Busienei et al., 2019). Similarly, Exum et al. (2019) reported that open defection in bushes or near water bodies was practised in different regions across Uganda. Failure to maintain cleanliness of the pit latrine was found to be a significant factor contributing to the descent from the sanitation ladder back to open defecation in Uganda (Kwiringira et al., 2014). On privacy during latrine use, Nunbogu et al. (2019) reported that, in Ghana, the assurance of privacy increased latrine usage by 42.5%.

Hand washing facilities were reported to be common in most households but their use after visiting the toilet was considered by study participants to be limited which was in agreement with findings of Byamukama (2019) who reported that the practice of hand washing after using the toilet was low in Uganda (52%), with only 14% using soap. Lack of hand washing and poor personal hygiene presents a risk to infections with *T. solium* cysticercosis to the tapeworm carriers through the direct ingestion of eggs or to other household members through contamination of food and/or water. In a review on the availability of hand washing facilities in East Africa countries using demographic health surveys, Kisaakye et al. (2021) noted the Uganda had the least availability at 59.2%. The promotion of hand washing and improved personal hygiene is done by community leaders and VHTs but may have not been achieving the desired impact.

The results of this study indicate that there was a positive attitude towards deworming especially in children, but the practice is not common. There was low awareness on whether adults need to deworm regularly with few discussants noting that they do deworm occasionally. Deworming can break the *T. solium* transmission cycle by killing the adult tapeworms in humans and preventing environmental contamination. The commonly used and available deworming drugs in Uganda are Albendazole which may need a 3-day regime for treating taeniasis (Ash et al., 2017; de Kaminsky, 1991) and mebendazole for treating *Enterobius vermicularis* (threadworms also called pin worms), *Trichuris trichiura* (whipworms), *Ascaris lumbricoides* (roundworm) and *Necator americanus or Ancylostoma duodenale* (hookworms) (Keystone & Murdoch, 1979). It was noted that school age children were dewormed annually in school and during child health days using praziquantel to control schistosomiasis. A single dose of praziquantel at 10mg/kg has been shown to be effective against *T. solium* taeniasis (Camacho et al., 1991) and is the recommended drug of choice (WHO, 2021b). The effect of the MDA campaign on the prevalence of taeniasis and incidences of *T.solium* cysticercosis in Uganda need to be evaluated as was done in Tanzania (Braae et al., 2016).

Pig farmers had good knowledge and awareness on the importance of pig confinement in control of diseases but keeping pigs on free range was still practised. There were also misconceptions and beliefs on pig confinement with the belief that confined pigs do not grow well which may be case if confined pigs are poorly fed as reported by Dione et al. (2014). Efforts to improve adoption of pig confinement should also consider the barriers faced by farmers including availability of resources to construct pig pens and buy feeds for the confined pigs and lack of price incentives for properly raised pigs. Similar findings on barriers to pig confinement were reported in Zambia (Thys et al., 2016). An option could be to promote simple pig pen designs that could be constructed using locally available materials and alternative, more accessible feeds for pigs, such as forage and silage-based diets. These type of feeds were shown to reduce cost and yet had relatively good average daily gain (ADG)(Carter et al., 2018).Levy et al. (2014) concluded that small scale traders who could feed non-commercial feeds to pigs to attain a high ADG and could bargain with traders for better prices were likely to benefit from semi-intensive pig farming. Additionally, the traditional pig rearing sector was shown to be more sustainable than intensive pig rearing system (Lekule & Kyvsgaard, 2003a). Kabululu et al. (2018) noted an improvement in pig confinement after an intervention which trained farmers through demonstration on the construction of an improved pig pen and pig feed formulation. Results from the current study also show that pig traders demand smaller pigs (lower weight) due to the lower uptake of pig meat in the rural areas and possibly because they lack refrigeration services and would have to sell the entire carcass in one day or two. Pig farmers in Uganda reared pigs as a form of saving to be sold for liquid cash to cover school fees or emergencies (Ouma et al., 2015). To ensure profitability for the enterprise by selling the pigs at the specified time or when a certain weight is attained, farmers may need alternatives for liquid cash to cover emergencies and other household expenditures.

Meat inspection by government officials was reported to be irregular in the rural villages, only being conducted during holiday months when many pigs are slaughtered. Meat inspection of pigs slaughtered by the butchers across the district was reported to be irregular and ineffective due to lack of a centralized slaughter place, lack of transport for the meat inspectors, and political interference. Thys et al. (2016) reported similar challenges to meat inspection in Zambia. The traders did not mind if the carcass is not inspected, they went ahead and sold to buyers unless they an inspection stampwas demanded as was the case for Kampala consumers. Local consumers only checked meat for physical quality attributes and not infections like cysts. These findings were similar to Roesel et al. (2019) who reported in detail the attributes consumers in Uganda consider before buying both raw and/or ready to eat pork which included cleanliness, moderate fat layer, freshness, colour, texture and smell of the meat in order of importance.

On the other hand, traders mainly inspect live pigs for signs of African Swine Fever (ASF) and external parasites. These findings do not agree with results obtained by Ouma et al., (2021) who showed that traders inspected pigs for *T. solium* cysticercosis through tongue palpation in Masaka and Bukedea districts, Uganda. This contrast may be because the study focused on districts where traders buy pigs and transport to Kampala while in the current study the traders majorly bought and slaughtered for local consumption. The motivation to inspect for ASF may be due to fear of spreading the infections which may lead to market closure and animal movement restrictions adversely affecting their businesses. This shows that the priority for traders is the effect diseases on their business but not necessarily on the risk of contracting zoonotic diseases through consumption of uninspected meat. The failure of the meat inspection system in the study area may mean that pork consumers are at risk of infection with taeniasis and consequently neurocysticercosis. Roesel et al. (2016) also reported challenges in meat inspection and law enforcement in an analysis of Wambizzi slaughterhouse in Kampala including meat inspectors arriving late when slaughtering had already been done.

Stomach upsets, vomiting, and diarrhoea were reported as the main effects of consuming half cooked pork. There was generally low knowledge levels and awareness on the risk of getting taeniasis by eating half cooked pork. Households practised different methods of preparing pork at home similar to findings by Roesel et al. (2019). Health education with messages on cooking/roasting coupled with enforcement of standards on the sale of ready to eat food may be needed to lower the risk of exposure of consumers to infective meat.

Generally, there was good motivation to adopt mass drug administration, pig vaccination plus deworming with oxfendazole and health education as proposed strategies to control *T. solium* infections. For the MDAs, sensitization on the programs and accessibility by people in the rural villages was reported to be important to overcome the barrier of transport to health centres and the lack of awareness. The availability of the deworming drugs was also cited as a challenge by the human health professional. This may require streamlining of the existing deworming drug supply channels and funding mechanisms. Farmers were willing to adopt the vaccination of pigs and treatment with oxfendazole. The main motivation was the ability of oxfendazole to treat other gastrointestinal nematodes which are a more serious constraint to the farmers. However, availability of the drugs especially in small packages that are affordable was emphasized. These findings are consistent with reports on willingness to pay for TSOL18 vaccine and oxfendazole by farmers in Uganda (Dione et al., 2021). In contrast, Thys et al. (2016) reported unwillingness to pay for the TSOL18 vaccine by farmers in Zambia although the latter did not have the oxfendazole component. Farmers were highly receptive of health education but emphasized on the need to use methods which can reach many people including mass media like radio, posters in public places as well as the use of community leaders and VHTs for sensitization.

5.5 Conclusion

1. Pig farmers, community leaders and pig/pork traders had almost no knowledge. *solium* infections and were often confused regarding the differences existing between *T. solium* and other gastro-intestinal infections in pigs and humans.

2. Pig confinement, pit latrine construction, coverage, maintenance and sustained use were influenced by cultural, socio-economic, and physical/ environmental factors of study population and area.

3. Proper sensitization programmes and health education interventions should target all, but with material appropriately focused to suit stakeholder category. Reminders or nudges may be needed to ensure that any increase in knowledge translates to changes in practice.

CHAPTER SIX

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATION

This section summarizes the findings and discussions and suggests recommendations on the consideration of context in designing *T. solium* control strategies and the opportunities available for integrated control.

6.1 General discussion

Context, defined as the circumstances and characteristics underpinning interventions' planning implementation and evaluation interact with interventions to influence their success. The influence of context and enabling environment varies depending on the study type and scale of implementation. The different study categories include - those focused on testing the efficacy of interventions under controlled conditions, studies testing effectiveness of control intervention under "real-world" conditions, and finally studies focused on implementation or scale-up of interventions. The design of efficacy studies increases the chances of detecting effect if it exists but does not consider wider contextual factors that may influence an intervention's effect at scale. Epidemiological factors, socio-economic, cultural and service and organization factors may influence efficacy studies albeit to a limited extent. Effectiveness studies are performed under "real world conditions" and therefore the contextual factors are of greater influence on their successful implementation. The contextual factors influencing effectiveness studies included - epidemiological, socio-economic, cultural, geographical and environment, service and organizational factors, policy and strategies on *T. solium* control and historical factors. Establishing and understanding the epidemiological context of the study area was shown to beimportant in guiding the process of setting goals, choosing the intervention to implement, and deciding the methods and diagnostics techniques to use to measure impact. Social and economic factors have far reaching effects on the delivery and sustainability of intervention programs. Cultural factors particularly beliefs, attitudes and practices including religious beliefs may influence the effect of the interventions in different ways and they are often deep rooted and hard to change. Geographical and environmental factors also played a role in supporting or influencing the success of *T. solium* interventions by affecting coverage and uptake. Service and organizational context including local capacity in terms of availability of qualified staff to carry out the project activities were also considered important. For *T. solium* control interventions, a variety of stakeholders are required for their successful implementation. They include national government ministries and agencies (ministries of livestock and health, research approval commissions, and One Health coordinating unit) if present. At the project site level, local government officials, community leaders, community members including diseases victims and community-based organizations (CBOS) should be represented. Policy, strategies, and legal guidelines in a study country could affect the choice and delivery of interventions since they must be embedded within the country laws and guidelines. Historical factors, for example influence of past involvement of target community in disease control interventions, positive or negative experiences with certain programs could impact delivery of interventions positively or negatively. Leveraging the integration of *T. solium* control interventions with other country programs on control of other NTDs or wider human and animal health issues can also indirectly afford *T. solium* control the much-needed government support. The understanding of the economic barriers to control may require conducting ex-ante and ex-post economic analysis before implementation. Rapid assessment techniques can also be used to understand the socioeconomic determinants which may affect the success of *T. solium* control interventions.

The three studies grouped as implementation research studies tried to identify the contextual factors which may have affected the implementation of the interventions and tried to adapt to emerging contextual issues during the project life cycle. The contextual factors included epidemiological, socio-economic, cultural, geographical and environmental factors, service and organizational, policies and strategies and financial factors.

Integration approaches to control pig parasites may help leverage farmers’ recognition that infection with worms was an important constraint to pig production and requires deworming. Understanding the co-infection status of pigs with different parasites is important to create evidence to support integration approaches. Several other studies reporting prevalence and risk factors of PCC and GI parasites separately exist for different parts of Uganda, but to the best of our knowledge the co-infection of pigs with GI parasites and PCC with the aim of guiding integrated control of both parasites has not been studied in Uganda. The animal level prevalence was similar to that reported by Kungu et al. (2017a) for rural settings in Uganda which were 7.8% by HP10 ELISA and 3.0% by Apdia ELISA and was below prevalences reported in other regions of Africa. In Mozambique, Pondja et al. (2010) reported 34.9%, Eshitera et al. (2012) reported 32.8% in western Kenya, Pouedet et al. (2002) reported 11% in Cameroon, and recently, Shongwe et al. (2020) reported 7% in South Africa. All studies utilized HP10 or apDia commercial Ag-ELISA. Hoima District had a higher prevalence of PCC at the animal level compared to Kamuli District. The apparent prevalence in Kamuli District was significantly lower than that previously reported by Nsadha et al. (2014) who reported a prevalence level of 28.1% (n=63) by HP10 Ag ELISA with a sensitivity of 89.5% and specificity of 74% (Porphyre et al., 2016; Thomas et al., 2016b). The low specificity of ELISA tests used may have resulted in high levels of false positives, and the apparent prevalence determined by HP10 ELISA seemed to often be higher than those by

B158/B60 Ag ELISA (now commercialized by ApDia). The ApDia Ag ELISA has a sensitivity of 86.7% and specificity of 94.7% (Dorny et al., 2004) and was used in the current study. The results of the study identified an association between seropositivity and knowledge that pigs can get infected by eating dirty feed. Other studies have found that knowledge of the transmission cycle was associated with reduced risk of the disease but not knowledge on risk of feeding contaminated feeds (Kungu et al. 2017). Although pig farmers may have knowledge on the health risk of feeding pigs dirty or contaminated feeds, resource constraints and the reliance on crop residues and swill as feed for pigs may mean infective materials are introduced to the pigs even when they are confined or tethered. Additionally, other changes in practices need to be accompanied by capital investments like construction of pig pens and toilets which may lead to lack of change in practice even after knowledge uptake in regions with limited resources (Sarti & Rajshekhar, 2003). The high proportion of co-infection of pigs with GI parasites and PCC reported in this study presents an opportunity to use integrated approaches to control both parasites. Farmers in Uganda recognize infection with worms as a major constraint to pig production but not so for PCC and have been found to extensively practice deworming of pigs to control internal parasites. Promotion of regular deworming using appropriate anthelmintic and inclusion of oxfendazole as part of the deworming regime can help control GI parasite infections while at the same time controlling PCC infections.

Among the various type of stakeholders targeted, pig farmers had the lowest level of knowledge specifically on *T. solium* infections although there was confusion of the pork tapeworm with other pig gastrointestinal helminths. This could be because farmers could easily identify infection of pigs with worms through physical symptoms such as stunted growth, reduced weight gain, emaciation and identification of the nematodes in pig faeces. A limited number of participants were aware about tapeworm infection in children but not in adults and since the participants could not clearly describe the worms seen in the faeces , these could be other intestinal helminths which have been reported in school going children in Uganda (Adriko et al., 2018; Kabatereine et al., 1997). Although, there was high pit latrine coverage in the study districts, many of them were poorly constructed. Many of the pit latrines were made of materials available mostly for free from the local environment due to the high cost of commercial construction materials. Dissemination of information and enforcement of latrine construction and use without capital investments may not be sufficient to increase coverage and sustained use. Further, gendered roles on latrine construction and maintenance should be considered when designing interventions to increase pit latrine coverage and use. Open defecation which a known risk factor for *T. solium* cysticercosis and other infections was still practised especially by the elderly, children and in some instances some household members. Free roaming pigs may easily access and eat faeces as they scavenge, or eggs could be introduced to the pigs through feedstuffs such as sweet potato vines and tubers perpetuating the transmission of the parasite. Open defection in gardens could contaminate fruits, vegetables and cassava or sweet potato tubers presenting a risk for neurocysticercosis to household members. Lack of hand washing, and poor personal hygiene presents a risk to infections with *T. solium* cysticercosis to the tapeworm carriers through the direct ingestion of eggs or to other household members through contamination of food and/or water. Deworming of children and adults could break the *T. solium* transmission cycle by killing the adult tapeworms in humans and preventing environmental contamination, but low awareness was identified. Meat inspection for pigs slaughtered by the butchers across the district was reported to be irregular and ineffective due to lack of a centralized slaughter place, transport for the meat inspectors and political interference. There was generally low knowledge levels and awareness on the risk of getting taeniasis by eating undercooked pork. Households practised different methods of preparing pork at home. The likelihood of consuming poorly cooked pork may be high if pork was consumed at local pork joints where traders reported several barriers to cooking pork well. There was good acceptability of mass drug administration, pig vaccination plus deworming with oxfendazole and health education as community-based strategies to control *T. solium* infections. For the MDAs, sensitization on the programs and accessibility by people in the rural villages was reported to be important to overcome the barrier of transport to health centres and lack of awareness.

6.2 Conclusions

1. The effect of contextual factors on efficacy, effectiveness and scale-up studies varies and the factors interact to influence the implementation and outcomes of *T. solium* control projects. These factors include - epidemiological factors including baseline and end-line outcomes measures, socioeconomic and cultural characteristics of target participants encompassing local knowledge, attitude and perceptions, geographical and environmental factors, service, and organization including stakeholder roles and their engagement.
2. *T. solium* cysticercosis in pigs was more prevalent in Hoima District than in Kamuli District. The prevalence of PCC in Kamuli appears to be decreasing as compared to previous studies in the same area possibly due to the ongoing improvements in the pig husbandry practices, increased latrine coverage across Kamuli or adoption of MDA programs targeting neglected tropical diseases (NTDs).
3. Knowledge that pigs can get infected by eating dirty feeds was found to be a significant predictor for *T. solium cysticercosis* seropositivity at household level. The prevalence for infection with any gastrointestinal parasite was high and similar across the two districts. There was also a high likelihood of infection of pigs with multiple helminth infections and PCC.

4. Among the stakeholder, farmers, traders, and community leaders had the least level of knowledge and awareness on *T. solium* infections and transmission. Their knowledge was confounded with knowledge on other pig gastrointestinal infections.
5. Pit latrine construction, coverage, maintenance, and sustained use was determined by the cultural and social economic characteristics of the target population and to some extent the physical characteristics of the target area.
6. Pig confinement was influenced by socio-economic, cultural as well physical and environmental factors. Pork was relatively well prepared at household level, but there was a possibility of consuming it undercooked, or poorly roasted, in pork joints.
7. The three proposed *T. solium* control interventions for implementation at community level were widely acceptable to the local stakeholders but with conditions for their successful adoption including cost subsidization, and proper sensitization.

6.3 Recommendations

1. Although, it might be challenging to fulfill all the contextual factors discussed, those considering rolling out interventions should consistently evaluate and consider context in the planning, implementation, and evaluation stages. The pre-project analysis of the different domains of context at inception and planning should evolve into a written strategy for their mitigation during implementation.
2. Since deworming was practised by many farmers in the study districts, the high rate of co-infection presents an opportunity for integrated control using oxfendazole which can eliminate both *T. solium* cysts and some pig gastrointestinal helminths. Further studies are required to test the feasibility of use of oxfendazole and cost benefit analysis in the control of *T. solium* cysticercosis and some of the gastrointestinal worms in pigs.

3. Health education interventions should target all the stakeholders but with tailor made content for each stakeholder category to improve their knowledge which may translate to change of practices.
4. Since knowledge does not always translate to practice, innovative ways of triggering change of practice may be necessary, for example, nudges (reminders), incentives and dis-incentives to reinforce good practices and deter negative practices as well as infrastructural investments to support change in practices.

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APPENDICES

Appendix 1: Study outcomes table: S1 Table, S2 Table, S3 Table.

S1 Table: Interventions on efficacy of drugs against *T. solium* infections in humans and pigs

Study ID	Target population and study site	Intervention	Features of study area at implementation	Conceptual framework/impact pathway	Methodology/ study design	Outcomes/findings	Challenges encountered and opportunities	Comments from KII
Kaminsky et al., 1991	Honduras; 2% of inhabitants in 15 rural communities; 56 individuals who were found to be infected with taeniasis	Administration of albendazole to people; drug donated by private company; individuals treated with 400mg of albendazole for 3 days and followed at 5 days, 60 and 90 days	The participants were not cooperating; area endemic to T. solium and T. saginata; limited coverage of the population; no information on engagement of stakeholders and sensitization	Aim was to test efficacy of albendazole to treat Taeniasis, evaluation done absence of eggs or proglottides in faeces using KATO cellophane thick smear, scotch tape perianal swab	Baseline conducted and positive people given albendazole at 400mg/kg	2 % to 0%- all individuals were negative at 60 and 90 days	unreliability of diagnostic method acknowledged, poor recovery of strobila, poor cooperation from study participants; unreality acknowledged -KATO reliability of 80% and combination the two methods 88% reliability; poor collaboration by the study subjects hence poor monitoring of proglottides	Not interviewed
Keilbach et al., 1989	Los sauces village, Guerrero, Mexico; 900 individuals received praziquantel, 60 % coverage; follow up after 4 months for pigs and 1 year for change in KAPs after education	health education and praziquantel and niclosamide for those with NCC; education delivered through meetings, lectures and demonstrations;	Worked with local research institute and university who provided technicians, nurses and minimum laboratory facilities; pigs are slaughtered at home and sold to village butcheries. Sometimes loaded into trucks and transported to other villages. No meat inspection	Evaluation of the intervention by prevalence by tongue palpation and ELISA and KAPS; Behaviour and attitude did not change after 2 years; knowledge improved slightly;	sensitization, coprological examination and ELISA, treatment with 5mg praziquantel and niclosamide for people with NCC, tongue examination of 200 pigs and ELISA, examination of soil samples	11% of pigs were positive at the final end of the evaluation by tongue palpation. Prevalence increased; in humans prevalence reduced from 3 to 0 %; after 2 years 2% of adults and 76% of children understood life cycle of taenia solium and cause of HCC in humans and PCC in pigs	illiteracy levels were high, and people did not want give up their traditional ways; taeniasis and HCC not appreciated as a major health problem,low percentage of treated people, open defaction and continued consumption of infected meat explain the increase prevalence of PCC.	Not interviewed

Study ID	Target population and study site	Intervention	Features of study area at implementation	Conceptual framework/impact pathway	Methodology/ study design	Outcomes/findings	Challenges encountered and opportunities	Comments from KII
Li et al., 2012	Sichuan Province, Yajiang county, China; 117 individuals with suspected taeniasis, 72 were male and 43 were female, follow-up 10 months to 22 months post-treatment	pumpkin seed and areca extract to treat taeniasis	Funded by regional government; worked with Yajiang County Centers for Disease Control (CDC) involved in sensitization	Evaluation by curative effect- number releasing full worms and those releasing segments measured by Microscopy and CoproPCR	A community-based study, Patients in the study group were given 3 different compounds in order at 40 min to 1 h intervals, including 120 g of peeled raw pumpkin seeds, 200 ml areca nut extract for an adult patient, and magnesium sulfate solution at a dose of 0.5 g/kg body weight.	Following treatment, 40 (88.9%) of 45 cases discharged whole tapeworms, indicating an 88.9% of cure rate, with a 95% credibility interval of 79.7–98.1%, and 2 (4.4%) expelled incomplete strobila, whereas the other 3 cases did not expel worms or proglottids 91 (79.1%) released whole tapeworms 4 (3.5%) expelled incomplete strobila,	The anthelminthic agent in the areca nut proved to be arecoline, The antiparasitic component in pumpkin seeds was identified as cucurbitine; treatment with traditional Chinese medicine was effective; side effects gastrointestinal upset and dizziness,	Not interviewed
Molinari et al., 1997	Guerrero State, Mexico; 12 months for 6 villages and again after another 12 months 4 villages of the 6 vaccinated at 12 months	vaccination with antigenic extract from T. solium metacestode	poor living conditions; no conventional abattoirs, no physicians; Worked with university students	Testing systemic vaccination of pigs; if enough number of animals are immunized; the parasite might be eliminated over time and integration is possible; the systemic vaccination of pigs concept has been adopted for the new vaccine TSOL18.	17 villages selected, 2650 inspected by tongue palpation and vaccinated;6 villages selected for subsequent vaccination; third vaccination done in 4 of the 6 villages	at second vaccination among 971 inspected pigs, 12 were found to be cysticercotic (mean 1.1 _+ 1.01 SD, 1.2%, P < 0.05) and (mean 0.45 + 0.45 SD, 0.46%, P < 0.05). All positive pigs were new cases aged 6 - 8 months. prevalence of porcine cysticercosis	More advanced and effective vaccine has since been developed.	Not interviewed
Study ID	**Target population and study site**	**Intervention**	**Features of study area at implementation**	**Conceptual framework/impact pathway**	**Methodology/ study design**	**Outcomes/findings**	**Challenges encountered and opportunities**	**Comments from KII**
Morales et al., 2008	Morelos, Sierra de Huautla rural community, Mexico; 62 % that is 562 pigs	Vaccination of pigs with S3Pvac; it's a recombinant M13 phage version of the anti-cysticercosis tripeptide vaccine	Trained technicians did the tongue inspection; over 25% no latrine;water from well, river and tap water; over 50% use river; 90% of pigs roam free;over 70% kept for sale and the remaining for consumption	Test efficacy evaluated by PCC prevalence by tongue palpation, PCC prevalence by necropsy and number of cysticerci in each carcass	Sixteen rural communities were selected from the 25 in the area. half the members of each litter were immunized with S3Pvac-Phage vaccine described above and half with placebo (saline)	cysticercosis was diagnosed in 12 pigs (3.9%) of the vaccinated group and in 29 pigs (13.0%) of the control group, corresponding to a vaccine efficacy of 70%. There now a new vaccine for PCC	198 in control and 319 in treatment group- consumption, death, natural death or reproduction before necropsy at 27 months 89 lost in control and 110 lost in treatment; the huge costs of synthetic	Not interviewed

							peptide technology make S3Pvac production unaffordable	
Ertel et al., 2017	Mbeya region in Tanzania; 79 participants from health- and agriculture sector- study subjects in group sessions with up to 17 participants per group.	health education using the vicious worm	A total of 79 study subjects were included in the study, hereof58 (73%) employed in the agriculture sector and 21 (27%) in the health sector. Of the study subjects, 17 (22%) were females and62 (78%) were males. Mean age was 36 years (range: 22–59 years, SD = 10).	evaluation of the efficacy of the vicious worm education tool measured by change in KAPs; follow-up study was conducted only after two weeks, measurement of long term effects would be desirable	The study involved the following sessions:(1) a prequestionnaire to assess the study subjects' baseline knowledge regarding T. solium, (2) individual health education with 'The Vicious Worm' for 1½ h, (3) a post questionnaire (identical to the prequestionnaire)	77% (95% CI: 67.7–86.3) had significantly improved (p < 0.001) their knowledge score immediately after the health education, and for 70% (95% CI: 59.7–80.3) the improvement persisted two weeks after (p = 0.001); The veterinarians had the highest mean knowledge score and the agriculture/livestock diploma students the lowest	The study subjects found the program educative and appealing due to the useful and practical information provided and its depiction of African settings. Some suggested supplement leaflets or similar information material for use in rural areas	Not interviewed
Study ID	**Target population and study site**	**Intervention**	**Features of study area at implementation**	**Conceptual framework/impact pathway**	**Methodology/ study design**	**Outcomes/findings**	**Challenges encountered and opportunities**	**Comments from KII**
Garcia et al., 2006	Huancayo, Quilcas district in Peru; 5,658 resident individuals and 716 pigs; coverage was 75%, ranging from 69% to 80%.	MDA with praziquantel in humans and oxfendazole in pigs	key village leaders, village leaders consulted the community on willingness to participate, sensitization to groups of villagers conducted	Outcomes were evaluated every 4 months after the intervention for a total of 20 months; Only through active participation of peasants it can be expected that an intervention program be sustained, and educational programs be accepted. Evaluation by comparing incidence rates (seroconversion in pigs who were seronegative 4 months before) in treatment versus control villages	The control intervention consisted of one round of mass chemotherapy for intestinal tapeworm infection in humans with a single dose of 5 mg/kg of praziquantel and two rounds of mass chemotherapy for porcine cysticercosis with a single dose of 30 mg/kg of oxfendazole	clear effect in decreasing prevalence (odds ratio, 0.51; P < 0.001) and incidence (odds ratio, 0.39; P0.013) in the treatment area after the intervention	very high proportion of pigs were sampled, principally because hog cholera vaccines and veterinary attention gained the support of the population and sustained it throughout the study. There were only a few refusals from cases where an animal coincidentally died soon after a sampling campaign and the family attributed the death of the animal to the	

							blood sampling	
Gonzales et al., 2001	Casacancha, Peru	single dose oxfendazole treatment for pigs	cysticercosis endemicity and long-term successful collaboration with villagers during previous surveys.	Evaluated eight weeks after treatment by checking acquisition of cysts (viable or degenerated) or seroconversion by EITB. Aim was to see if pigs with cysticercosis can acquire new infections after being treated with OFZ.	an experimental study pigs were treated with a single oral dose of 30 mg/kg of OFZ given as a veterinary aqueous suspension. Treated pigs were kept here for eight weeks after treatment	New infections were detected by serology in 15 (47%) of 32 control pigs, and by the presence of cysts in 12 (38%) of 32. Among these 12 pigs, viable cysts were found in seven carcasses; efficacy of OFX shown	One treated and nine control pigs were not recovered because of various reasons, mostly because villagers sold or slaughtered them for consumption. A minor drawback in the use of OFZ is that some cysts may survive in the pig's brain after treatment.	not interviewed
Study ID	**Target population and study site**	**Intervention**	**Features of study area at implementation**	**Conceptual framework/impact pathway**	**Methodology/ study design**	**Outcomes/findings**	**Challenges encountered and opportunities**	**Comments from KII**
Huerta et al., 2001	Huatlatlauca and Tepetzetzintla, in the state of Puebla, Mexico	Vaccination of pigs with Synthetic peptide vaccine	open defection practiced; local pork meat consumption and extensive domestic pig slaughtering	Efficacy of a chemically synthesized vaccine evaluated by necropsy 10 to 12 months after vaccination.	a controlled field trial with a control group	The results indicate 52.6% efficiency of the vaccine in reducing the number of infected pigs and 97.9% reduction of the total parasite load. Cysts reduced from 15.8 to 7.5%. At 95% level of confidence	Of all these, 18 vaccinated and 20 control pigs died of causes not related to vaccination nor to cysticercosis and were excluded from the study	Not interviewed
Mwidunda et al., 2015	Mbulu district, Tanzania; 60 schools (30 primary, 30 secondary) in Mbulu district.	Health education	School children and teachers were involved.	Health education to school children evaluated 12 months with assessments by	A cluster randomised controlled health education intervention trial	The intervention improved knowledge about human cysticercosis the most, followed	large variations in the baseline knowledge and attitudes	Not interviewed
Study ID	**Target population and study site**	**Intervention**	**Features of study area at implementation**	**Conceptual framework/impact pathway**	**Methodology/ study design**	**Outcomes/findings**	**Challenges encountered and opportunities**	**Comments from KII**
Jayashi et al., 2012	Morropon, Piura, Peru; Pairs of pigs (n = 137) comprising one vaccinated and one control animal 19.7% (54/274) loss to follow up	vaccination using a combination of two recombinant antigens, TSOL16 and TSOL18,	Did not involve a lot of stakeholders except district level leaders and households; no community meetings for sensitization; no plans for scaling up mentioned	Evaluation of the efficacy of the vaccine under natural conditions evaluation by the total number of cysts and the number of viable cysts. Using an effective vaccine in pigs would remove the source of	a pair-matched vaccination trial with 7 months	From the 113 animals vaccinated with the TSOL16–TSOL18 vaccine, 93.8% (106/113) pigs were free of infection. There was a significant 99.7% reduction (Wilcoxon signed-rank test, $p < 0.01$) in the total number	Immunization with the TSOL16–TSOL18 vaccines has the potential to control T. solium transmission in areas where the disease is endemic	Worked with local contact person who was known in the area

				tapeworm infection in humans, breaking the parasite's life cycle and indirectly eliminating the causative agent of human neurocysticercosis		of cysts in the vaccinated group (Total number of cysticerci = 83, mean = 11.9, median = 6, range = 1–54). There was a significant 99.9% (Wilcoxon signed-rank test, $p < 0.01$) reduction in the number of viable cysts in the vaccinated group (viable cysts = 3, mean = 1.5) versus the animals in the control group (viable cysts = 33,416, mean = 2227.7).		
Sciutto et al., 2006	Cuentepec in Mexico; 476 piglets - 2 months old were considered but 381 included	Vaccination with synthetic peptide vaccine S3Pvac against PCC in pigs	Free roaming pigs and open defection; local consumption of uninspected and cysticercotic pork; no mention of stakeholders involved	Baseline conducted by tongue palpation and necropsy of sentinel pigs; single and 2 doses of vaccine;	Randomised control trial	prevalence sentinel pigs, before and after the vaccination study, did not change significantly; a single vaccination is not enough	Loss to follow-up 215 pigs = 56% sold or missing; low sensitivity of 50% of tongue palpation; labour intensive and not cost effective; time-frame of the vaccination trial made no difference detected	No interview
Allan et al., 1997	municipality of Quesada, Santa Gertrudis and Eltule villages in Guetamala; 1513 individuals (74.9%) coverage	Mass drug administration with niclosamide with magnesium sulphate purgative	Pigs left to roam free; 26% in Santa Gertrudis and 67% in EL Tule open defecated; baseline conducted; niclosamide considered over praziquantel to avoid contraindication with people with NCC; no mention of stakeholders involved	Intervention evaluated by prevalence of taeniasis and PCC by EITB and EPG of *T. solium* eggs after 10 months; reduction of taeniasis will lead to reduction in PCC and HCC; no plans on sustainability or scaling up	A before and after intervention study; niclosamide administered to all consenting individuals	Prevalence changed from 3.5% at baseline and 1% at endline, $p<0.0004$; PCC declined from 55% before treatment to 7%	MDA consideration; Select an appropriate drug, percentage coverage of the population by treatment, and the appropriate intervention interval if multiple treatments are applied. Optimal retreatment interval not determined; PCC prevalence remained high; human	Not interviewed

							behaviour is a critical factor	
Chung et al., 1991	Nanao District, Ilan County, Taiwan; 66 cases (27 males and 39 females, from 9 to 74 years of age)	Efficacy of Albendazole	Cases identified by questionnaire and passing of proglottides; Private company donated albendazole; no information on stakeholders engaged. Scaling not recommended because drug is not efficacious	Aim was to evaluate efficacy of albendazole in treating evaluated using cure rate ; no recommendation for scaling because the drug was not effective against taeniasis	A field trial; (1) 400 mg x 1 day, (2) 800 mg x 1 day, (3) 800 mg x 2 days, (4) 800 mg x 3 days, (5) 1200 mg x 2 days and (6) 1200 mg x 3 days. The above six regimens were given to 30, 8, 14, 4, 6 and 4 patients, respectively. re-treatment with atabrine (= mepacrine, quinacrine) (male, 1.2 g; female, 1.0 g) was conducted.	cure rate of 50% of patients who had received 800 mg x 3 days, 1200 mg x 2 days, or 1200 mg x 3 days; in 14.3% of those given 800 mg x 2 days; and 0% of those who received 400 mg x 1 day or 800 mg x 1 day	Study show albendazole is not effective against taeniasis	Not interviewed
Cruz et al., 1990	GonzanamaandCatamayo in Loja and Balsas and Marcabelli in El Oro provinces, Ecuador; total of 10173 people treated;12.3% of total population treated	Population based treatment of taeniasis with praziquantel	provincial authorities and local community councils or leaders consulted in organization of the study;National University in Loja- provided 64 auxiliary staff, as follows: seven physicians, two veterinarians, one public health specialist, 26 students, three social workers, seven sanitary inspectors, six teachers, 9 volunteers, and three drivers; Praziquantel donated by private	Aim was on how to operationalize T. solium control by using praziquantel evaluated by Kato-Katz technique and pigs by necropsy; community showed interest for sustainability	3 phases; weighed and given a single dose of praziquantel 5 mg/kg. (90%) houses revisited during the 48-72 hours after treatment and questioned about any side-effects and whether they had expelled tapeworms. second treatment of 739 people (539 of whom had previously been treated and 200 of whom were treated for the first time)	1.6% meaning 0% prevalence at end line; a single dose of praziquantel (about 5mg/kg body weight) is effective	Long term evaluation needed; 90% of people wanted project to continue	Not interviewed

			company; local committee; a lot of sensitization was done through local radio and posters					

S2 Table: Studies focusing on testing effectiveness of control interventions

Study ID	**Target population and study site**	**Intervention**	**Features of study area at implementation**	**Conceptual framework/impact pathway**	**Methodology/ study design**	**Outcomes/findings**	**Challenges encountered and opportunities**	**Comments from KII**
Garcia et al., 2016	Tumbes, Peru; 10,753 humans and 17,102 pigs in phase 1 and 10,380 humans and 13,488 pigs and final scale up phase 3 107 villages, covering 81,170 humans and 55,638 pigs	Phase 1 screening of humans and pigs, antiparasitic treatment, prevention education, and pig replacement in 42 villages for 1 yr. Phase 2 mass treatment with mass screening and phase 3 mass treatment of humans along with the mass treatment and vaccination of pigs in a region	multi-institutional effort; both ministries of agriculture and health were involved demonstrating one health approach; personnel from the ministries carried out the activities. Region was highly endemic	Determining feasibility of regional elimination; effect measured by detailed necropsy to detect pigs with live, non-degenerated cysts capable of causing new infection after 1 year.	An entire region was covered in 3 phases with different interventions or modifications	incidence rate ratios, 0.78 [95% confidence interval {CI}, 0.64 to 0.95] and 0.79 [95% CI, 0.65 to 0.97], respectively; 14 (36.8%; 95% CI, 21.8 to 54.0) of humans were still infected 2 weeks after mass treatment in phase 1, as assessed by ELISA for coproantigen detection plus stool microscopy.	it is feasible to interrupt *T. solium* transmission on a regional scale, thereby preventing human and porcine cysticercosis; The reservoir of infection in the intermediate host was eliminated in 105 of 107 villages through a 1-year attack phase; elimination not maintained.	Not interviewed
Hobbs et al., 2018	Students from grades three to six at the Nyembe (Nyembe), Kondwelani (Chimvira) and Gunda (Herode) primary schools, Zambia. A total of 99 students participated in the three workshops:	Health education targeting school children	90 % but open defection still practiced; 98% of the region's estimated 66 000 pigs are reared under small-scale 'backyard' conditions; scavenging. No mention of stakeholders; no information on budget. delivery of the educational component required only a laptop, projector and small generator.	determine the impact education with the vicious worm program on knowledge uptake in primary school students, evaluate by change in knowledge from the baseline level ; no plans for scaling up	Pre and post intervention study	Post-questionnare. knowledge uptake of 11.5%. Increases of 10% or more were seen for 14 (82%) questions, and six (35%) increased by at least 25%. Increased knowledge was seen in seven of the eight QS1 categories (88%), with five (71%) increasing by 10% or more ($P < 0.05$). the key concepts for parasite control were better understood by the students after the educational workshops.	The differences in questionnaires used and the unavailability of individuals' response data from the Nyembe workshop prevented a comprehensive comparison of knowledge and knowledge uptake across the three study groups on the individual level.	Important to understand sociocultural context; work with all stakeholders; build capacity local staff
O'neal et al., 2014	Piura Province, Peru; 1058	Ring screening of	There was excellent	Treatment of people after ring screening	a controlled prospective	Over the entire study period the sero-	ring-screening for taeniasis may	Involve government

	residents in intervention village and 753 residents in control village= 1,811 people	people within 100 metres and treatment of positive ones with niclosamide	participation of local community; Pigs are typically allowed to roam unrestrained in the village to forage as this reduces or eliminates owner investment in feed. pigs reared as a source of income and meat protein; there was high degree of community involvenment.	and evaluation using incidence of exposure by sampling the pig population every 4 months for serum antibodies against cysticercosis using enzyme-linked immunoelectrotransfer blot.	interventional cohort pilot study. We treated participants with suspected or confirmed taeniasis with a single oral dose of niclosamide according to their weight conduct mass treatment and screening for taeniasis	incidence decreased 41% in the intervention community (incidence rate ratio [IRR] 0.59, 95% CI 0.41–0.87) and remained unchanged in the control village (IRR 1.01, 95% CI 0.70–1.47). There was 41% greater reduction in sero-incidence between baseline and study end in the intervention village compared to the control village (IRR 0.59, 95% CI 0.35–0.97). prevalence of taeniasis was nearly 4 times lower in the intervention village than in the control at study end (PR 0.28, 95% CI 0.08– 0.91).	reduce transmission of T. solium in a rural endemic area	and community. Hold open community meetings to sensitize community; work with other stakeholders including local NGOs. Collaboration was important

Study ID	**Target population and study site**	**Intervention**	**Features of study area at implementation**	**Conceptual framework/impact pathway**	**Methodology/ study design**	**Outcomes/findings**	**Challenges encountered and opportunities**	**Comments from KII**
Braae et al., 2016	Mbozi and Mbeya district, Tanzania	School-based mass drug administration (MDA) of praziquantel was carried out based on schistosomiasis Endemicity with a 36 months follow-up	village leaders, school headmasters, and head teachers involved in planning; there was high level of engagement between different stakeholders	Aim was to effects of the National Schistosomiasis Control Programme on prevalence of taeniosis and porcine cysticercosis over a four-year period in Tanzania. Evaluation by prevalence of taeniosis and porcine cysticercosis by B158/B60 Ag-ELISA	multiple cross-sectional surveys carried out. MDA of praziquantel at 40 mg/kg to school-aged children 3 times in Mbozi district and 2 times in Mbeya district by the NSCP. Stool samples were collected in 14 villages from the human population	significant decrease in prevalence (13% to 8%) of porcine cysticercosis (p = 0.002, OR 0.49, CI: 0.32–0.76) was reported in Mbozi. 36% drop in prevalence of porcine cysticercosis Mbozi district and 23% drop in Mbeya. Prevalence of taeniosis had dropped from 4.1% to 1.8%	National Schistosomiasis Control Programme (NSCP) by the government of Tanzania provided support framework for the work; elimination would require a one health approach. Integration with other national control programs may be cost effective but other targeted approaches are needed	Important to work with different stakeholders. Maintaining visibility in the project area is important to ensure sustained interest by local communities
Alexander et al., 2011	South India, Tamil Nadu, Kaniyambadi, a rural block	praziquantel, niclosamide and targeted therapy	The cost per person screened by stool testing for coproantigens was US $ 12, and the cost per case of taeniasis	Aim was to evaluate the cost-effectiveness of three strategies for the control of taeniasis in a community, in terms of cost per case	screening of stool samples for coproantigens by ELISA and therapy for positive. 2nd universal	mass therapy without screening for taeniasis would be the most economical strategy in terms of cost per case treated. For each strategy, costs	Mass therapy without screening; This option may be more cost-effective per case of taeniasis treated than the others but the acceptability,	Not interviewed

			detected was US $ 4051, The cost per person screened was US $ 10.8; cost of hospitalization for the above step, which was US $ 30 per stool-positive subject in our study.	treated. rate of taeniasis as detected by ELISA for coproantigen; evaluated by costs per case detected and treated for each and prevalence of taeniasis	screening using only stool microscopy followed by targeted therapy of stool positive persons. The third option would be mass treatment with oral niclosamide	per case treated are higher at low prevalence of taeniasis, with a sharp rise below 15%.	feasibility and actual costs in India would have to be explored. Integration with other STH control programs would increase cost effectiveness. response rate for obtaining stool samples was low	
Study ID	**Target population and study site**	**Intervention**	**Features of study area at implementation**	**Conceptual framework/impact pathway**	**Methodology/ study design**	**Outcomes/findings**	**Challenges encountered and opportunities**	**Comments from KII**
Anna et al., 2016	Phongsaly, in Mai District bordering Vietnam, Lao PDR. one village, 50/55 of permanent households (90.9%) households had at least one member eligible; over 75% of the eligible village pig population	Mass drug administration with a 3-day albendazole 400 mg to humans. At these times, and again in October 2014, eligible village pigs received TSOL18 vaccination and an oral dose of oxfendazole anthelmintic at 30 mg/kg,	local government medical personnel, project veterinary staff were involved in administering the MDA and monitoring. less than 20 percent have access to toilet, low-input production systems with many free ranging pigs. consumption of raw pork; village was not easily accessible during rainy season.	investigate T. solium control with treatment of both humans and pigs taeniasis prevalence were estimated via copro-antigen ELISA	A pilot study involving 2 rounds of community MDA with a 3-day albendazole 400 mg protocol, vaccination of pigs with the TSOL18 anti-cysticercosis vaccine and oral oxfendazole at 30 mg/kg	9/138 cases of taeniasis. Taeniid eggs were detected in only one of the post-interventions copro-antigen positive. A 78.7% reduction to 6.52% (95% C.I.3.4–9.5%) accounting for clustering and a finite population; true village post intervention prevalence was returned as 0% (95% C.I. 0–5.1%),	A monitoring and evaluation of progress. lack of adequate facilities in northern Lao PDR for large-scale fine dissection of pigs, post-mortem analyses to identify cysts were not possible. Despite covering over 85% of the eligible human population at each MDA, this only related to approximately 60% of the total village population and compliance is a challenge	Important to consider context when designing and planning for interventions, involve local community especially for therapeutic interventions. Empower them to make decisions; work with both ministry of health and livestock; there was good government support
Ngowi et al., 2007	People in 72 villages in Mbulu district Tanzania and evaluate in 42 villages	Health and pig management education intervention	Rural settings in Mbulu district, subsistence rearing of pigs as income source, no information on stakeholder involvement or policy environment	a financial benefit-cost analysis for the health education intervention, also effectiveness of the intervention reducing incidence rate of PCC; no plan for continuous reinforcement of the messages	Benefit-cost analysis of the intervention, effectiveness measured by reduced incidence of PCC by Ag-ELISA	Significant benefit of the intervention [NPV: US $3507 (95% CI: 3421 to 3591); IRR: 370%]. over 5 years, sensitivity analysis shows intervention will remain efficient over time, but follow-up was on for 4 months	Seasonality of feed availability led to drop out of 52% of baseline farmers, worry of outbreak of African Swine Fever in neighbouring regions; no mention of how they adjusted considering the challenges mentioned.	We have not been involving national stakeholders; no government funding; meat inspection guidelines exist but no meat inspectors; no policy on control of T. solium; superstitions in giving human samples

Ngowi et al., 2009	People in 72 villages in Mbulu district Tanzania and 9 public health officials	health-promotion strategy-the PRECEDE-PROCEED model	Rural settings in Mbulu district, process evaluation applied, community assessment conducted to inform design, only extension and health officials mentioned	Health promotion model used to design and evaluate intervention, process evaluation applied; no plan for continuous reinforcement of the messages	Process evaluation applying the PRECEDE-PROCEED model, incidence of PCC by Ag-ELISA and KAPs evaluation	20% reduction in consumption of cyst-infected pork, 43% reduction in incidence of PCC	Lack of holistic approach for example environmental health interventions, no public policy support; no attempt to involve other sectors in design and implementation.	Same as above
Ngowi et., 2011	Farmers Iringa Rural and Chunya districts in Tanzania	Health education - training by a trained livestock extension officer, a video show, and distribution of a leaflet and a booklet	Small scale pig rearing with sale to urban areas, extension worker and farmers mentioned as stakeholders, no mention of a baseline survey, only some terminology changed from the same messages used in another region	a quasi-experimental study design with pre- and post-intervention assessments of same respondents to obtain paired data. Change in KAPs taken to mean adoption; no plan for continuous reinforcement of the messages	Pre and post intervention of the same group	significant improvement in the knowledge and attitudes towards Taenia solium control ($P < 0.001$), no change in consuming infected pork 28.4% of the respondents informed that they would still consume it	Few women attended the training raising questions of reach, authors acknowledge most pigs are reared by women; implementers did not adapt to overcome this challenge. Meat inspection laws should be improved;	Same as above
Ngowi et al., 2008	Rural farmers in Mbulu district, Tanzania	Health education trial- video, leaflets, booklets, posters, and a training manual	Baseline survey conducted; no mention of stakeholders involved included livestock/agricultural extension officers (LFEO) and two health workers from psychiatry department and village leadership who helped identify target farmers	Measured effectiveness of health education by incidence of PCC and change in KAPs. Implementation process well explained; No plan for sustainability or scale-up of the intervention	a randomised community-controlled trial to measure effectiveness of health education using incidence of PCC by Ag-ELISA	incidence rate in the control group 10–12 months after the intervention was 69 (95% CI: 65, 72) per 100 pig-years and 25 (95% CI: 23, 28) per 100 pig years, and intervention group was 44 (95% CI: 41, 47) per 100 pig-years and 12 (95% CI: 11, 14) per 100 pig-years using Ag-ELISA and lingual examination, Knowledge on transmission improved >42%, consumption of infected pork reduced by 20%	livestock/agricultural extension officers and psychiatry department-local health workers not include in the farmers' training (Phase 2) because they were scheduled for other official duties at that time. Small sample size at evaluation due to loss to follow up	Same as above
Pondja et al., 2012	Ango´nia district, Mozambique	Oxfendazole (OXF) for PCC in pigs	Baseline survey on prevalence and KAPs; Free roaming pigs, Stakeholders involved; private company -Bayer-South Africa provided	A randomized controlled field trial to evaluate effectiveness of OXF using prevalence, incidence using Ag-ELISA and viable cysts at necropsy;	A randomized controlled field trial; evaluation by prevalence, incidence and viable cysts.	66.7% of controls positive, 21.4% of the T1 and 9.1% of the T2 pigs positive. Incidence of PCC lower in treated pigs as compared to controls;	Ag-ELISA not good for monitoring effectiveness because cysticercal antigen levels take long to disappear from circulation and	No interview

			the oxfendazole, community authorities and farmers, NGO: no involvement of local community in design and no policy environment info.	impact shown in the short run but no plans for scaling or sustainability in the study area		(OR = 0.14; 95% CI: 0.05–0.36) or at 9 months of age (OR = 0.05; 95% CI: 0.02–0.16) after OXF treatment.	may not detect brain cysts.	
Sarti et al., 2000	Atotonilco village in Morelos state in Mexico; one district, 87% of the 3007 population treated with praziquantel	mass treatment with praziquantel 5mg/kg as a single dose for Taeniasis	Field staff, laboratory staff, community members mentioned as stakeholders; 31% toilet coverage and improved to 64 after intervention, outdoor defecation reduced; baseline conducted; no mention of community involvement in design; no mention of working with MOH; improvement of sanitation unrelated to intervention.	Treatment of Taeniasis will ultimately reduce incidences of PCC and NCC; mass chemotherapy against taeniasis can have impact in the short and long term; Late-onset convulsive crisis and specific antibodies can indicate HCC and exposure; no plans for scaling	A population-based intervention study with baseline at T0 and evaluation by prevalence of taeniasis, NCC and PCC after 42 months	11.3% p=0.85 change at T1 and 52.4 p=0.5 change by T2 by tongue palpation and 4=54.5% p= 0.05 change at T1 and 29.6% p=0.4 by ELISA of PCC; 56% by egg detection p=0.160 and 61.2% change by coproantigen p= 0.020 of Taeniasis; Late-onset general seizures decreased 70%.	Half dose 5mg/kg used to avoid exacerbation of neurocysticercosis but author notes this will increase direct costs; recommended is 10mg/kg; close supervision required in administration	No interview
Steinmann et al., 2011	Menghai county/ Nongyang village in China; compliance was estimated to be 80%. Recruitment was to be stopped once 400 individuals had been enrolled. 5 years and above	single-dose and triple-dose albendazole and mebendazole against soil-transmitted helminths and Taenia spp	Stakeholders; village head, village committee, and local health care officials, WHO regional office in Hanoi, Vietnam; no mention of involvement of target community in design; no mention of scaling	The intervention was not intended to evaluate effect on T. solium but STH as proxy; Kato-Katz thick smears- Eggs per gram of stool (EPG) and egg reduction rates (ERRs); An open-label trial design was adhered to due to the complexities and high cost for implementing a double-blind trial in a field setting;	a randomized controlled trial	69% (95% CI: 55–81%) of hook worm infections cured with single dose of albendazole, while 31% (95% CI: 20–45%) was cured with triple dose. triple-dose albendazole cured significantly more hookworm infections (92%, 95% CI: 81–98%) than triple dose mebendazole (58%, 95% CI: 46–71%). Single dose less efficacious against *Tichuris trichiura* (mebendazole: 40%, albendazole: 34%., single dose of either	assessment of the locally endemic STHs, and the adaptation of the employed anthelminthic drug regimens to the prevailing situation emphasized; opportunity for integrating different interventions for several parasites demonstrated	Important to work with all actors – animal and public health; policy support important and align with programs working in the target area; integration is important and we demonstrated it can work; working with international organizations like WHO can help; meat inspection

						drug cured half and triple dose cured all infection- triple dose albend. prevalece=o and 1.2 for triple dose mebend.		should be enforced; prepare practical messages for the health education intervention
Steinmann et al.,2015	Nanwen upper, Nanwen lower and Mangguo new villages in Menghai county in China; coverage rates around 80–90% of the eligible population	health education and MDA with albendazole and latrine construction	Stakeholders; local village doctors and leaders, local construction company; no latrines but village had access to clean water; no mention of involvement of target community in design	Outcomes measures; measure of prevalence of Taeniasis and EPG; target was also om other STHs; no mention of plans to maintain sustainability and scaling up.	a prospective community-based intervention study	per village for Taenia spp. Prevalence reduced by 54.7, 22.6 and 60.3% in Namwen upper, Namwen lower and Mangguo new village respectively; Only bi-annual treatment combined with latrine construction and health education significantly impacted on the prevalence of Taenia spp.,	China government subsidizes local infrastructure development, an opportunity for similar projects; relaxation of intervention led to raise in prevalence of the STHs; MDA needed more frequently; different effects of the drug on different STHs; The rather high cost of about US$ 300 per latrine leading to sustainability issues	Same as above
Alexander et al., 2012	Tamil Nadu State/Kaniyambadi, a rural development Block in India; 120 households; 10 – 20 students from 3 high schools	Health education to school children and community	Pigs roamed free; One-third of the houses in the area had toilets; drinking water was available; Implementation done by trained community volunteers and a qualified health educator; community not involved in design; senior social workers and doctors involved to evaluate the intervention; no mention of national stakeholders	Health education program to school children and community; evaluated through KAPs after 6 months; baseline survey was conducted; change in seroprevalence of PCC and taeniasis not evaluated; no mention of scale-up	A health education strategy designed based on baseline survey;messages were delivered through street plays, songs, interactive discussions, posters, banners and handbills; study design not stated	a 46% increase in the overall score of knowledge and practices; washing hands with soap and water after using toilet improved by 3.6(23.7% to 86.4%), open defecation decreased by 23%; Awareness about the method of spread of taeniasis and cysticercosis improved by 3 times(from 10.5% to 28.6%) p<0.001	Evaluation not done on same subjects; change in seroprevalence of PCC and Taeniasis not evaluated	Not interviewed
Ash et al., 2017	Phongsaly village 700km north of Vientiane LAO PDR; 300 people in 60	MDA with albendazole 400mg/kg over 3 consecutive days	Low sanitation, open defecation, subsistence pig rearing; consumption of raw and/or	Reduce prevalence of taeniasis and other helminths using one health approach; 2 rounds of MDA with 400mg/kg	A before and after study; McMaster technique used for STH and molecular	after MDA1 overall 66% P < 0.0001). prevalence reduction for individual parasite species for A. lumbricoides	Existence of school deworming programme may have compromised compliance for	We worked with ministry of health and ministry of agriculture but depends

	households; 64% coverage; n=146/298 received 3 doses in MDA1 and n=173/293 received 3 doses in MDA2; 108 loss to follow-up		undercooked pork, practiced; Some stakeholders; Lao PDR Ministry of Health Department for Communicable Disease Control, Department of Hygiene and Prevention, and the Neglected Tropical Diseases administered drug and monitored; baseline survey conducted.	albendazole – has broad spectrum; after 5 months	techniques for T. solium and hookworms	(95.6%; P < 0.0001), hookworm (83.4%; P < 0.0001), Taenia spp. (79.4%; P = 0.012), T. trichiura (69.2%; P < 0.0001). After MDA2 Overall parasite prevalence 20.8%, greatest reduction in individual parasite species was detected for Taenia spp. (100%)	children; varying proportion of unidentified faecal samples were obtained in the study; eligibility and compliance of community members, and the level of re-infection which is attained post treatment were challenges; need for integration	on the intervention whether pigs or humans; STH and T. solium have high priority in LAO; involving local community will ensure sustainability.
Assana et al., 2010	Mayo-Danay administrative department in Cameroon; 120 piglets pairs-vaccinated and not vaccinated	Vaccination of pigs with TSOL18 and administration of oxfendazole	Pigs roam free during dry season; more than 40% of houses that keep pigs do not have latrines; baseline conducted through tongue palpation; no mention of stakeholders; no involvement of local community in design	Vaccination to protect uninfected pigs and oxfendazole to treat infected pigs; Assessment by prevalence and number of viable cysts and ELISA for antibody titres; provide proof-of-principle; no mention of scaling	A field trail for TSOL18 vaccine; vaccinate piglets at 2–3 months of age and give a booster immunization 4 weeks later. At the time of the second immunization, the pigs were given oxfendazole	Reduction in the prevalence of infection from 19.6% (19/97) in paired control pigs to 0% (0/97) in paired vaccinated pigs (P < 0.0001). Control group had 20% prevalence	Combined application of TSOL18 vaccination and a single oxfendazole treatment has potential to eliminate T. solium	Not interviewed
Beam et al., 2018	Piura province, Peru; 1,250 pigs in the cohort including 615 (49.2%) in the intervention villages and 635 (50.8%) in the control	Household- and school-based education about the parasite life cycle and methods to prevent infection were offered in all villages	67.5% latrine coverage; free roaming pigs Stakeholders: community health workers, health post, residents, school children, key actors (political and religious authorities, pig farmers and vendors, ministry of health office of epidemiology;	study outcome was porcine sero-incidence measured every 4 months; secondary outcomes included the prevalence of porcine cysticercosis and human taeniasis at study end; surveillance and reporting system was also tested	prospective trial; A local surveillance and response system was established in intervention villages along with a campaign to promote reporting of infected pigs	no difference in the sero-incidence after 12 months in the intervention versus control villages	There was some level of community involvement	Not interviewed
Beam et al., 2019	Peru; Workshop participation of at least 1 adult	Health education	Context not reported; no mention of stakeholders;	workshop included presentation of local economic and epidemiologic data, followed by	Before and after study	Knowledge of human-to-pig transmission increased by 38%(P< 0.01) for	Discussing control interventions with local community can help in design	Not interviewed

	per household was 41/84 (49%), 25/34 (74%), 29/68 (43%), and 15/49 (31%) per village in the 4 villages		volunteers involved;	hands-on participation in pig dissection, group discussion of the T. solium life cycle, and viewing of eggs and nascent tapeworms with light microscopes; use of local evidence and experiential learning positively affected knowledge		attendees and 23%(P< 0.01) for non-attendees, knowledge of pig-to-human transmission increased by 42% (P < 0.01) for workshop attendees and 9% (P < 0.05) for non-attendees, Only workshop attendees had gains in knowledge of human-to-human transmission (12%, P < 0.05 versus 5%, P = 0.13)		
Camacho et al.,1991	La Curva, Navolato in the state of Sinaloa in Mexico; Over 70% of the population over five years of age	large scale treatment of the population with praziquantel at 10mg/kg	25% sanitation; free roaming and tethering of pigs; no mention of scalability but praziquantel recommended	Evaluation of the intervention in people was by measuring prevalence of PCC in pigs and Taeniasis by microscopy and ELISA	census, stool sampling and blood from humans and inspection of pig by tongue palpation, treatment with praziquantel and then evaluation after 1 year	from 1.32% of taeniasis at baseline and no case at end line (0%); Relative risk decreased from 2.95 (95% CI = 1.56-5.56) before treatment to 0.85 (95% CI = 0.2- 3.4) after treatment.	There was administration of other antiparasitic drugs in the same area for other STHs; there could have been complication in people with NCC because of the dose of praziquantel used.	Not interviewed
Kabululu et al., 2018	Mbozi and Mbeya Rural districts in Tanzania; 92, 51 and 78 pigs during baseline, first follow-up and second follow-up rounds respectively, which is 16.4% of all eligible pigs in the selected households	Oxfendazole for T. solium and ivermectin for other nematodes and animal husbandry education;	Majority semi-confined pigs; District Livestock Office, local administrative leaders, Farmers, local mason/ carpenter, extension officers Oxfendazole donated by private company; a baseline was conducted	integrated intervention in the control of endo- and ectoparasites with oxfendazole for specifically T. solium; evaluation by Ag-ELISA, McMaster faecal egg counting technique and body searches/skin scrapings; no mention of plans for scaling up; sustainability was a problem – reduced compliance	A repeated cross-sectional group randomization design was used; specific training and technology transfer of improved pig pens, improved pig feeds and feeding practices, and treatment with OFZ and IVM; control group received ivermectin treatment only; 3 model pens constructed; 2 follow-ups 7 months apart each.	12.6% in intervention and 9.8% in control;59.3% for intervention and 70.4 in control for GI helminths; no significant change p= 0.429. Fluctuations in sero-prevalence of PC were observed in both groups where prevalence increased from baseline to first follow-up and declined from first to second follow-up; significant difference between the two groups in change of prevalence of T. suis	underestimation because serology is not able to provide quantitative data; reduced compliance as this was a field study	Not interviewed

S 3Table: Studies focusing on implementation research for control interventions or scale-up of interventions

Study ID	Target population and study site	Intervention	Features of study area at implementation	Conceptual framework/impact pathway	Methodology/ study design	Outcomes/findings	Challenges encountered and opportunities	Comments from KII
Braae et al., 2017	Mbeya and Mbozi district, Tanzania; 34% School age children in 14 villages	MDA with praziquantel	54, 46, and 38% of the sampled people had no access to toilet Stakeholders; village leaders, school headmasters and head teachers. National Schistosomiasis Control Programme (NSCP), district health officer and the medical doctor; school-based MDA with praziquantel is carried out as part of the National Schistosomiasis Control Programme (NSCP) in schistosomiasis endemic districts part of support programs	MDA to school-aged children (SAC) combined with 'track and treat' of taeniosis cases in the general population; being in the community for extended time helped maintain support.	Three cross-sectional population-based surveys were performed in 2012 (R0), 2013 (R1), and 2014 (R2). 'Track and treat' for positive individuals	a drop in infection at R1 (P < 0.001, OR 0.49, CI: 0.32–0.74)twelve months after the MDA in both districts and at R2 ten months after the second round of MDA in Mbozi and 22 months after the first MDA (P < 0.001, OR 0.38, CI: 0.22–0.62); in some cases prevalence did not change	The persistence of infections means one health approach is needed; engaging community over long time helped support activities during implementation	Guidelines on meat inspection exist but not enforced; during implementation maintain visibility in the community; engage community and explain project
Bulaya et al., 2015	Katete District, Zambia; 9 villages in Katete district	Community led total sanitation (CLTS) to control *Taenia solium* cysticercosis	open defecation practiced; free roaming pigs; Stakeholders;Ministry of Local Government and Housing, trained CLTS champions,local district veterinary authorities and local leaders; CLTS implemented by national government and Unicef	Improvement of sanitation will lead to reduced taeniasis and PCC prevalence; A trainer of trainers (ToT) workshop was conducted with District Council employees on how to train CLTS champions and trigger. PCC examined by B158/B60 Ag-ELISA after 8 mon.	A comparative research was conducted with pre and post-intervention assessments	Prevalence of PCC 13.5% and 16.4% after the intervention; At baseline, 29.1% of the respondents were unaware of pig cysticercosis compared to 56.8% at post-intervention.latrine use was at 41 (93.2%) at baseline and 62(84.9%) post-intervention;32 new latrines constructed	The validity due to possibility of cross reactions with *T. hydatigena* metacestodes; an anthropological study provided insights; availability of women for the sessions due to seasonality; longer monitoring period needed	Many stakeholders were involved because it had backing of national govt.;local communities and leadership need to be involved more; no national policy on control of *T. solium*

Carabin et al., 2018	Boulkiemdé, Sanguié, and Nayala provinces, Burkina Faso;60 villages- 80 households, 60 participants in each village; 522 participants in intervention; 513 in control	community-based educational programme; intervention developed using PRECEDE-PROCEED;	13.5% use toilet; pigs confined but fed feaces in one province village chiefs and household chiefs in planning; Water and Sanitation for Africa (WSA); development of the intervention cost US$31 538; intervention was low-cost, culturally appropriate intervention; intervention developed in a participatory way;	Evaluation of the intervention by incidence and prevalence of human *Taenia solium* cysticercosis by B158/B60 Ag-ELISA; 39/705 (5·5%) new toilets; increase community self-efficacy through a Self-esteem, Associative strengths, Resourcefulness, Action planning, Responsibility (SARAR) approach via the Participatory Hygiene and Sanitation Transformation (PHAST) model	a cluster-randomised controlled trial	decrease (adjusted prevalence proportion ratio 0·84, 95% CrI 0·59–1·18) to post-randomization cumulative incidence (adjusted cumulative incidence ratio 0·65, 95% CrI 0·39–1·05)	weaker to no effects were observed when the smaller database of analytical sample 1 was used. Implementation research required going forward	Not interviewed

Appendix 2:PRISMA flow chart

Section/topic	#	Checklist item	Reported on page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	Title Pg. 47
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	Abstract pg.47
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	Introduction pg. 48& 49
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	methods and pg.50 and 51
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	methods pg. 50
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	methods and pg.50 and 51
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	methods and pg.50 and 51
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	methods and pg.50 and 51
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	methods and pg.50 and 51

Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	methods and pg.50 and 51
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	methods and pg.50 and 51
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	Methods pg.51 para 2
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	N/A
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	No metanalysis was done
Section/topic	**#**	**Checklist item**	**Reported on page #**
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	Methods pg.51 para. 2
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	No metanalysis or meta-regression was done
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	Results and discussion pg.56, 57 para. 1, figure 1&2
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	Supplementary material S1Table, S2Table &S3Table in Appendix 1
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	Page 51 para 2
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	Results and discussion pg59 to 79. No forest plot
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	N/A
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	Page 51, para 2
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	N/A
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	Results and discussion pg59 to 79.
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	N/A
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	Conclusion pg80
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	Reported under acknowledgement

Appendix 3:Taenia solium cross-sectional survey household questionnaire.

(I am going to ask a few questions about your pigs. I am interested to know how you keep and feed your pigs. I will also ask some questions about water and other hygienic issues. The aim of my questions is to find out the risk for your pigs to get parasites which could also affect you and your family. Before we go into questions about your pigs, I would like to start by getting to know you.) (Go through the consent process before starting)

District________________________

Subcounty_____________________

Village__________________________

HHD ID.________________________ (*same as in UPG project)*

Name of respondent___________________________________

Age of respondent_________________________

Gender of survey respondent (1=male, 2=female, 3=other)	
Relationship of respondent to household head (code a)	
Respondent relationship (code a)	
1 = household head 2 = spouse (wife or husband) of household head 3 = child of household head 4 = parent of household head 5 = sibling of household head 6 = other family member, specify [_______________________] 7 = herdsman / labourer 8 = household help / maid -77 = other non-family member, specify [________________________]	

1. Pig housing. Indicate how pigs are mainly housed / kept. If the farmer does not keep that type of pig (e.g. boars) put -99 for not applicable.

	Rainy season housing (code a)		Dry season housing (code a)	
	Day	Night	Day	Night
Piglets	[____] [_____]	[____] [_____]	[____] [_____]	[____] [_____]
Sows	[____] [_____]	[____] [_____]	[____] [_____]	[____] [_____]
Boar	[____] [_____]	[____] [_____]	[____] [_____]	[____] [_____]

Main way of housing /keeping pigs (code a)
1= free range 2= tethered 3= housed, -77=other, specify[____]

*2.. Feeding practices.*Complete the following in relation to feeding of the pigs over the last 2 years

Feed-type / source	Feed used in dry season (1=yes, 0=no)	Feed used in wet season (1=yes, 0=no)	Source – list up to the main two (code a)
Maize bran			[___] [___]
Rice bran			[___] [___]
Commercial concentrate			[___] [___]
Sweet potato vines			[___] [___]
Home mixed rations			[___] [___]
Sweet potato roots			[___] [___]
Cassava leave (raw)			[___] [___]
Cassava leaves (boiled)			[___] [___]
Yam leaves			[___] [___]
Amaranth spp.			[___] [___]
Wandering jew / pig weed			[___] [___]
Kitchen leftovers (boiled swill)			[___] [___]
Kitchen leftovers (unboiled swill)			[___] [___]
Brewery waste			[___] [___]
Commercial feeds			[___] [___]
Spurge			[___] [___]
Banana peels			[___] [___]
Napier grass			[___] [___]
Grazing, specify what on			[___] [___]

[________________________]			
Other, specify [________________________]			[___] [___]
Other, specify [________________________]			[___] [___]
Other, specify [________________________]			[___] [___]
Other, specify [________________________]			[___] [___]

Source (code a)
1 = on own farm 2 = on another farm, used for free 3 = on another farm, paid for 4 = communal - accessed for free 5 = communal - paid for 6 = purchased from feed supplier / feed shop 7 = purchased from feed miller 8 = obtained for free from feed miller 9 = purchased from brewery 10 = obtained for free from brewery 11 =purchased from restaurant / hotel / school / hospital 12 = obtained for free from restaurant / hotel / school / hospital -77 = other, specify below [_______________________]

3. Pig watering

Water source	**Source in rainy season (1= yes, 0 = no)**	**Source in dry season (1= yes, 0 = no)**
S01q01.piped water into the house		
S01q02 piped water to yard/plot		
S01q03.public tap/standpipe		

S01q04.Private borehole/well		
S01q05.Public borehole/well		
S01q06.natural spring		
S01q07.lake		
S01q08.Dam or pond		
S01q09.rainwater collection		
S01q10.Other (specify)		

S04.Pig access to infective material/human faeces.

S02q01.Are faeces (animal or human) including pig waste visible where pigs are? (Yes/No)	
S02q03.How often do you deworm your pigs? (Code a) 0= Never 2 After every 2 months 2 3 months interval 3 Once a month 4 => 3-month interval 5 =When advised by the vet doctor/buyer (e.g in the case of contract farming) 77= other___________________	
S02q04.When did you last de-worm your pigs *(code b)* 1= in the last week 2= in the last one month 3= in the last 3 months 4 = more than 3 months 5 = I can't remember 77=other	
S02q05.Which deworming drug did you use the last time? (code c)(*ask to see the bottle and put down the active ingredient name)* 1= Albendazole 2= Levamisole 3= ivermectin 4= Piperazine 77= other _________________	

5. Pig slaughter and pork consumption

S03q01.Where are your pigs usually slaughtered? (code a) 1= Home 2= Slaughter slab 3= private Pig abattoir 4= government pig abattoir 5= Local butchery 6= Pork Centre 77= Other______________________	
S03q02. If they don't answer home – ask 'Have you ever slaughtered pigs at home by yourself? YES/NO	
S03q03.If home or yes is an answer: When you slaughtered pigs at home, was it inspected by a government officer? Yes/No	
S03q04. If No, who does the inspection? 1= Myself 2= Husband/wife/son 3= Local animal health worker 4= Meat inspector from local slaughter house 5 = The trader who bought the pig 77= Other________________	
S03q05.The last time it was inspected, did you have topay for the inspection? Yes/No	
S03q06.Do you or anyone else in your household eat pork (your own or bought)?YES/NO	
S03q07.If Yes. How does the pork you eat prepared? (code c)	
S03q08.Where do you consume ready to eat pork? (Code d)	
S03q08.Do you consume ready to eat pork with raw vegetables including salsa? (Code h)\ 0= Never 1= Always 2= Sometimes 77 = other	
S03q09. Do you consume pork with raw vegetables including salsa? YES/NO	
S03q10.Where do you purchase RAW pork?	
S03q11.Have you ever seen a blue stamp on the meat you buy? YES/NO	
S03q12.Do you know what this means? YES/NO	
S03q13.If yes what does the blue stamp mean?	
S03q14.Do you inspect meat before buying? YES/NO	
S03q15.What do you look for when inspecting pork before buying (code g).	

1= colour of the meat 2= mixture of red meat and fat 3 = blue/purple stamp 4 = cleanliness 77 = other	
Place of slaughter (Code a)	**Meat inspection (code b)**
1= Home 2= Slaughter slab 3= Pig abattoir 4= Local butchery/pork center 77= Other______________________	1= Myself 2= Husband/wife/son 3= Local animal health worker 4= Meat inspector from local slaughter house 77= Other________________
Pork consumed (code c)	**Raw pork (code e)**
1= Raw 2= Boiled 3= Fried 4 = Boil and then fried 77= Other____________ **Ready to eat pork (code d)** 1=home 2= Local hotel 3= Pork joint 4= Supermarket 5= during a village function/event 77= Other ______________	1= Slaughter house/slab 2= Local butchery 3= Wet market 4= Supermarket 5= pork joint 77= Other____________

6.Knowledge of Taenia solium infections

S04q01 Have you heard of infected pork meat (pork with cysts/pork measles)? YES/NO	
S04q02.What does it look like?	
So403.What happens if you eat this pork meat?	
S04q05. How do pigs get this disease?	
S04q06. Have you heard of epileptic seizures cause by neurocysticercosis?	
S04q07. How is it acquired?	
Prevent Taenia solium (code f)	

1= Deworming 2= Vaccination 3= Confining my pigs 4= Use of herbs e.g papaya or pumpkin seeds 77= Other____________ 98= Don't know

7.Household Hygiene and Health

S05q01.Do you usually boil drinking water? YES/NO	
S05q02.What kind of toilet facility do members of your household usually use? *(Use code b)*	
S05q03.Do you have children below 5 years YES/NO	
S05q04.If yes, do they use the toilets to relieve themselves YES/NO	
S05q05.If No where do they relieve themselves? *(Code c)*	
S05q06.Do you share this facility with other households? YES/NO	
S05q07.Is there a hand-washing area <u>with soap</u> in or next to the toilet? YES/NO	
S05q08.Is there a hand-washing area <u>with soap/detergent</u> in or next to your kitchen? YES/NO	
S05q09.Do you have a kitchen garden YES/NO	
S05q10.Do you use faeces/sludge as manure in the kitchen garden? Yes/No	
S05q11.When did you last deworm yourself and other family members *(code d)*	
S05q12.Which deworming drugs do you use? *(code e) (ask to see the label on the container/package)*	
S05q13.Where do you get the deworming drugs from? *(Code f)*	
S05q14.Do you pay for the drugs YES/NO	
S05q15.If yes, how much per dose in UGX	
S05q16.Have your children ever been dewormed in school YES/NO	
S05q17.If yes, when was the last time they were dewormed? *(Code g)*	
S05q18. Has any of your family members had/have worm infection problem/infection? YES/NO	

S05Q19. If yes, how did you know they had/have worm problem/infection?	
Source of drinking water (code a)	***Toilet facility (code b)***
1= Bottled water 2= piped water into dwelling 3= piped water to yard/plot 4= public tap/standpipe 5= borehole/well 6= Surface water (pond, lake) 7= natural spring 8= rainwater collection 77= other ______________________	1= Flushing 2= Bucket flushing 3= Pit latrine 4= Field/no facility 77= Other_____________________ **No toilet (code c)** 1= in the nearby bush 2= in the farm 3=on the ground/potty and throw in pit latrine 4=on the ground/potty and throw field/farm 5=on diaper and throw in pit latrine 6=on diaper and throw in the field/farm 7 = on diaper and throw in dumping pit 77= other
Last deworming (code d)	***Source of deworming drugs (code f)***
1= Never 2= 3 months interval 3= Once a month 77= other_________________ **Deworming drugs used (code e)** 1= Albendazole 2= Praziquantel 77= Others __________________	1= Local government clinic/dispensary 2= Local private clinic 3= Local pharmacy/ chemist 4= Distributed by government 5= Distributed by NGO 77= other_________________ **Last deworming in school (code g)** 1= < 3 month ago 2= > 3 months ago 3= Can’t remember 99= Don’t know

8.Observation questions

S06q01.Do you see a toilet facility in the compound? *(Enumerator to observe)* YES/NO	
S06q02.Does the toilet facility have a enclosed wall and door? *(Enumerator to observe)* YES/NO	
S06q03.Do you see a clear path leading to the toilet facility or signs of recent use of the facility? *(Enumerator to observe)* YES/NO	
S06q04.Are faeces (animal or human) visible in compound *(Enumerator to observe)* (Yes/No)	
S06q05.Is there a hand-washing area with soap in or next to the toilet? *(Enumerator to observe)* YES/NO	
S06q06.Do you see pigs or piglets roaming around the compound? *(Enumerator to observe)* YES/NO	
S06q07.Can pigs get in contact with latrines/human faeces? (Yes/No) *(check whether pig are confined and if toilet has complete walls and a door)*	

END

Appendix 4: Data collection protocol for objective three: All stakeholder categories

Workshop guide for farmers/community members (group discussion) – probes have been included in brackets

1. What is *Taenia solium/the pork tapeworm? (use local language for tapeworm)*
   probes
   a. perceived causes, how do pigs get infected,
   b. how do humans get infected (probe for Taeniasis and NCC?
   c. How the diseases manifests in humans and pigs,
   d. use the *T. solium* poster to explain the three diseases and how they are acquired – Taeniasis, NCC and PCC)
2. Give overall results from the cross-sectional study (prevalence, risk factors).
   Probes
   a. What does it mean when cysts are found in pig meat?
   b. people/children pass worms pieces in faeces) and how they can be used?
   c. when you eat undercooked meat with cysts,
   d. what disease can you end up getting
3. How can we control the tape worm infections (allow them brainstorm and use the poster to show possible control options (the 6 stages to break the cycle)?
   probes
   a. what can a mother/farmer/butcher do to break the cycle? -
   b. Give an overview of the control options which can be done at community level and discuss their roles as outline below
   a. Mass drug administration (MDA) in humans -PZQ (In general population or in School Age Children (SAC) – when children or adults are given deworming tablets by some NGOs or the government. **What can motivate you to participate in this option (deworming for other soil transmitted helminths?)**
   b. Vaccine + oxfendazole (OXF) in pigs-*(vaccine-TSOL18 kills cysts in pigs, OXF kills T. solium cysts and kills other pig worms)* (will you be willing to pay for the vaccine? **What can motivate you to adopt this option? Is worm infection in pigs a problem in thisarea? Will use of a drug that kills both pig worms and *pork tapeworm* in pigs be suitable for you? why?**
   c. Health education – on pig husbandry and household and community hygiene – use the T. solium poster (**why confining pigs and feeding them clean feed is important, why use of toilet and washing hands is important**
4. Do all the households in your village have toilets

   Probes

   a. percentage of households with toilets,
   b. are the toilets well-constructed?
   c. what is your role in construction of toilets?
   d. who cleans the toilets,
   e. Who enforces the use of toilet in your home and in your village?

5. Are there programs by government or NGOs supporting construction of toilets or hygienic infrastructure?)

probes

a. Where is there is latrine, which materials did people use,
b. who taught them how to build it,
c. do they like the design, if not, what do they not like,
d. do children use the toilet?
e. How do they empty and maintain them?
f. do they have hand washing areas next to the toilets?

6. Where do households without toilets relieve themselves? (**Probe for households with children below five years, elderly, men and women**)
7. Are there households with toilets and do not use them? (**Probe for what makes people not to use toilets even if they are available)**
8. What are the constraints to toilet construction?
   Probes
   a. How do the constraints affect men and women?

b. what can be done to increase construction and use of toilets

9. Do the local marketplaces have a public toilet (**Probe to know where people relieve themselves while in the local markets, during village gathering/meetings)**
10. Are there free roaming pigs in your village?

Probes

a. What do they feed on when scavenging?
b. Why the pigs not housed?
c. What are the consequences of let pig roam around?

11. What do you do when you go to buy pork?

    Probes

    a. where do you buy,
    b. what do you do when you reach the place of buying?
    c. what do you look for in the meat before buying?
    d. What do you do if you don't like the meat?

12. Do you prepare pork in the house or you eat out?

Probes

a. How do you prepare your pork?
b. What are the effects of eating poorly cooked pork?
c. where do you buy the pork?
d. do you check for cysts when buying?

13. Do you deworm yourselves and family members? (**probe for drug used, where they get it from**

14. What do you think will make it easy for people to practice the control measures?

Workshop guide for meat inspectors/animal health assistants

1. What is Taenia solium?

Probes

a. perceived causes,
b. how is it transmitted to pigs and from pigs to humans?
c. how it manifests in humans and pigs,
d. what can a mother/farmer/butcher do to break the cycle?

2. How can we control these 3 diseases (allow them brainstorm and use the poster to show possible control options (the 6 stages to break the cycle)? Give an overview of the control options which can be done at community level and discuss their roles as outline below)

    d. Mass drug administration (MDA) in humans -PZQ (In general population or in School Age Children (SAC) – when children or adults are given deworming tablets.

    Probes

    What can motivate you to participate in this option (deworming for other soil transmitted helminths?)

    e. Vaccine + oxfendazole (OXF) in pigs-*(vaccine-TSOL18 kills cysts in pigs, OXF kills T. solium cysts and kills other pig worms)*

    Probes

    a. will farmers be willing to pay for the vaccine?
    b. What can motivate you to adopt this option?
    c. Is worm infection in pigs a problem in this area?
    d. Will use of a drug that kills both pig worms and *T. solium* in pigs be suitable for you? why?

    f. Health education – on pig husbandry and household and community hygiene – use the T. solium poster (why confining pigs and feeding them clean feed is important, why use of toilet and washing hands is important

3. Give overall results from the cross-sectional study and highlight the issues with the diagnostic method in terms of sensitivity and specificity (prevalence, risk factors). Brainstorm on the meaning of the results and how they can be used.
4. Have you ever received any training on detection of PCC **(probe for when by who, what were you trained on)?**
5. Have ever condemned pig carcass due to PCC?

Probes:

a. Which are the common reasons for condemning
b. what happens to the carcass?
c. who makes sure it disposed?

6. What do you do when you find cysts in pork?

    probes

    a. what advise you give to the butcher, do you condemn?
    b. If you condemn, how is the reaction by the trader/butcher/farmer

c. How do they recover the cost?
d. any other markets for the condemned pig,
e. do they fight back?
f. How do you ensure they don't get back to you?
g. Is there enough support from the government to protect you and how can it be improved?

7. Are there laws or acts which guide your work (which are they, what does the law say?)
8. How is the compliance of farmers on pig husbandry practices (housing, feeding and treatment/deworming)?
9. In your view what makes farmers not to adopt improved pig husbandry practices (Housing/feeding/deworming or treating)
10. Do you keep records when you treat pigs?

Probes

a. what do you include in the record?
b. how often do farmers call you to treat their pigs?
c. what are the common issues you handle?

11. What do you think will make it easy for people to practice the control measures?

Workshop guide for community human health assistants

12. What is Taenia solium?

Probes

e. perceived causes,
f. how is it transmitted to pigs and from pigs to humans?
g. how it manifests in humans and pigs,
h. what can a mother/farmer/butcher do to break the cycle?

13. How can we control these 3 diseases (allow them brainstorm and use the poster to show possible control options (the 6 stages to break the cycle)? Give an overview of the control options which can be done at community level and discuss their roles as outline below)
    g. Mass drug administration (MDA) in humans -PZQ (In general population or in School Age Children (SAC) – when children or adults are given deworming tablets.
    Probes
    What can motivate you to participate in this option (deworming for other soil transmitted helminths?)
    h. Vaccine + oxfendazole (OXF) in pigs-*(vaccine-TSOL18 kills cysts in pigs, OXF kills T. solium cysts and kills other pig worms)*
    Probes
        e. will farmers be willing to pay for the vaccine?
        f. What can motivate you to adopt this option?
        g. Is worm infection in pigs a problem in this area?
        h. Will use of a drug that kills both pig worms and *T. solium* in pigs be suitable for you? why?
    i. Health education – on pig husbandry and household and community hygiene – use the T. solium poster (why confining pigs and feeding them clean feed is important, why use of toilet and washing hands is important

14. Give overall results from the cross-sectional study and highlight the issues with the diagnostic method in terms of sensitivity and specificity (prevalence, risk factors). Brainstorm on the meaning of the results and how they can be used.

1. How many households have toilets in your area?
   Probes
   a. percentage of households with toilets,
   b. are the toilets well-constructed?
   c. What type of toilet are there in the subcounty?
   d. what is the role of men and women in construction of toilets?
   e. Are there programs by government or NGOs supporting construction of toilets or hygienic infrastructure?
2. Where do households without toilets relieve themselves?

Probes

a. households with children below five years, elderly, men and women
b. why do they not use toilets?
c. How do households dispose the waste?

3. Are there households with toilets and do not use them? **Why?**
4. What are the constraints to toilet construction? (**Probe to know how they affect men and women, what can be done to increase construction and use of toilets)**
5. Do the local marketplaces have a public toilet (**Probe to know where people relieve themselves while in the local markets, during village gathering/meetings)**
6. What programmes do you have which support deworming of households and children?
7. How do you support people with epilepsy (diagnosis, medication, community education to avoid stigmatization)?
8. What are the types or causes of epilepsy in the community? How many people have epilepsy in the community?

9. What do you think will make it easy for people to practice the control measures?

Workshop guide for traders (they operate as pig traders but also have a pork joint/butchery)

1. What is *Taenia solium*?

Probes

a. perceived causes,
b. how is it transmitted to pigs and from pigs to humans?
c. how it manifests in humans and pigs?
d. what can a mother/farmer/butcher do to break the cycle? - use the T. solium poster to explain the causal and impact pathways of the three diseases)

2. Give overall results from the cross-sectional study and highlight the issues with the diagnostic method in terms of sensitivity and specificity (prevalence, risk factors).
3. How can we control these 3 diseases (allow them brainstorm and use the poster to show possible control options (the 6 stages to break the cycle)? What do they think is their role in the steps? Give an overview of the control options which can be done at community level and discuss their roles as outline below)
   j. Mass drug administration (MDA) in humans -PZQ (In general population or in School Age Children (SAC) – when children or adults are given deworming tablets. What can motivate you to participate in this option (deworming for other soil transmitted helminths?)
   k. Vaccine + oxfendazole (OXF) in pigs-*(vaccine-TSOL18 kills cysts in pigs, OXF kills T. solium cysts and kills other pig worms)*
   Probes
   - will you be willing to pay for the vaccine?
   - What can motivate you to adopt this option?
   - Is worm infection in pigs a problem in this area?
   - Will use of a drug that kills both pig worms and *T. solium* in pigs be suitable for you? why?

   l. Health education – on pig husbandry and household and community hygiene – use the T. solium poster (why confining pigs and feeding them clean feed is important, why use of toilet and washing hands is important
4. What qualities do you look for when buying pigs? (What health criteria/health checks do you use)
5. Do you inspect for diseases (what diseases do you look for? How do you check whether the pig is sick? How do you inspect for PCC or cysts in pigs)
6. What will make it easier for you to do the health checks?

Probes

   a. provision of new technologies for testing at the farm,
   b. prove that the pigs have been treated/vaccinated e.g. vaccination certificate)
7. What do you do when you find cysts in pork?

Probes

   a. do you still buy?
   b. Do you buy at the same price?
   c. Where do you take that pig after buying?
8. Have you ever received any training on detection of cysts (probe for when by who, what were you trained on)?
9. If you slaughter pigs, where do you slaughter from (probe for private slaughter slab, private commercial slaughter slab, government slaughter slab/house).
10. What are your views about meat inspection by government?

Probes

a. is it important to be done?
b. Who does the inspection?
c. What happens if they are not available to inspect?
d. If the carcass does not pass the inspection,
e. what happens?

11. Are there laws or acts which prevent you from selling/trading in sick pigs or movement of pigs **(which are they, what does the law say? What does the government require from you)?**
12. What do you think will make it easy for people to practice the control measures? (include group ranking exercise

Workshop guide for community leaders (LC1 chairman/village leader)

1. What is Taenia solium?
   Probes
   a. perceived causes,

b. how is it transmitted to pigs and from pigs to humans?
c. how it manifests in humans and pigs?
d. what can a mother/farmer/butcher do to break the cycle? - use the T. solium poster to explain the causal and impact pathways of the three diseases)

2. Give overall results from the cross-sectional study and highlight the issues with the diagnostic method in terms of sensitivity and specificity (prevalence, risk factors). **Brainstorm on the meaning of the results and how they can be used.**
3. How can we control these 3 diseases (allow them brainstorm and use the poster to show possible control options (the 6 stages to break the cycle)? Give an overview of the control options which can be done at community level and discuss their roles as outline below)
   a. Mass drug administration (MDA) in humans -PZQ (In general population or in School Age Children (SAC) – when children or adults are given deworming tablets in mass. **What can motivate you to participate in this option (deworming for other soil transmitted helminths?)**
   b. Vaccine + oxfendazole (OXF) in pigs-*(vaccine-TSOL18 kills cysts in pigs, OXF kills T. solium cysts and kills other pig worms)* ***Probes***
   - will you be willing to pay for the vaccine?
   - What can motivate you to adopt this option?
   - Is worm infection in pigs a problem in this area?
   - Will use of a drug that kills both pig worms and *T. solium* in pigs be suitable for you? why?

   c. Health education – on pig husbandry and household and community hygiene – use the T. solium poster (why confining pigs and feeding them clean feed is important, why use of toilet and washing hands is important

4. How many households have toilets in your area

Probes

a. percentage of households with toilets,
b. are the toilets well-constructed?
c. what is the role of men and women in construction of toilets?
d. Are there programs by government or NGOs supporting construction of toilets or hygienic infrastructure?)

5. Where do households without toilets relieve themselves? **(Probe for households with children below five years, elderly, men and women)**
6. Where do households without toilets relieve themselves? **(Probe for households with children below five years, elderly, men and women) why do they not use toilets? How do households dispose the waste?**
7. Do the local marketplaces have a public toilet **(Probe to know where people relieve themselves while in the local markets, during village gathering/meetings)**
8. What is your role in the control of T. solium infections? (probe for role in promoting/ enforcing sanitation, community deworming programmes, pig husbandry e.g. preventing pigs from roaming, toilet use)
9. Has any of the above strategies been implemented in your village (probe for the scale/period, implementer and participation of the stakeholder or actor)

Workshop guide for people affected by diseases (epileptic patients)

1. What is Taenia solium? (Probe for perceived causes, how is it transmitted to pigs and from pigs to humans, how it manifests in humans and pigs, - use the T. solium poster to explain the three diseases)
2. How can we control these 3 diseases (allow them brainstorm and use the poster to show possible control options (the 6 stages to break the cycle)? What can a mother/pig farmer/meat inspector do to prevent the infections in humans or pigs
3. Are there people in your house or community who had tapeworm infections?
4. How did you know they had worm infections? How were they treated?
5. Do you eat pork?
6. Give overall results from the cross-sectional study and highlight the issues with the diagnostic method in terms of sensitivity and specificity (prevalence, risk factors). Brainstorm on the meaning of the results and how they can be used.
7. How did you come know that you had epilepsy (where were you diagnosed? How were you checked, what do you think made you sick)?what do other people say or believe made you sick?
8. How often have you had the seizures?
9. How do you manage the disease? (probe for medication, source of medication and cost)
10. Has having epilepsy changed your life in anyway? How do the other family members/community members treat you? (probe for; How has the disease affected you? (do you work currently? Are there things you used to do now you can't do? Does somebody have to take care of you? is there anything you would like to do but are not allowed to do? Do community members know you have epilepsy? Do they know how to help you if you have seizures? Are there other people in your village who have epilepsy

Key informant guide for district level governmental and non-governmental actors (DVO, DHO, IOWA, NARO, HOCADEO, Private Vet)

1. Use the *T. solium* poster to explain the parasite and the 3 diseases – Taeniasis, Porcine cysticercosis and Neurocysticercosis (probe first on what they understand about *T. solium* transmission)
2. Give overall results from the cross-sectional study and highlight the issues with the diagnostic method in terms of sensitivity and specificity (prevalence, risk factors). Brainstorm on the meaning of the results and how they can be used.

3. How can we control these 3 diseases (allow them brainstorm and use the poster to show possible control options (the 6 stages to break the cycle)? Give an overview of the control options which can be done at community level and discuss their roles as outline below)
    a. Mass drug administration (MDA) in humans -PZQ (In general population or in School Age Children (SAC) – when children or adults are given deworming tablets. What can motivate you to participate in this option (deworming for other soil transmitted helminths?)
    b. Vaccine + oxfendazole (OXF) in pigs-*(vaccine-TSOL18 kills cysts in pigs, OXF kills T. solium cysts and kills other pig worms)* (will you be willing to pay for the vaccine? What can motivate you to adopt this option? Is worm infection in pigs a problem in this area? Will use of a drug that kills both pig worms and *T. solium* in pigs be suitable for you? why?
    c. Health education – on pig husbandry and household and community hygiene – use the T. solium poster (why confining pigs and feeding them clean feed is important, why use of toilet and washing hands is important
4. Has any of the above strategies been implemented in your village (probe for the scale/period, implementer and participation of the stakeholder or actor)
5. Are there regulation which support the control of T. solium (what are these laws, do you play a role in enforcement?)
6. What activities do you do to support work zoonotic diseases (including *T. solium*) in your area of operation?
7. What is your role in the control of *T. solium* infections?
8. What is your role in creating support structures (allocating staff to the control initiatives, lobbying and procuring drugs) to support success of the interventions?
9. Do you work with other agencies or arms of government/NGOs/private sector (which are they, what type of data do you share?
10. What motivation will support your staff to participate in control activities (what are some the things which could make staff unwilling to participate)
11. What do you think are some of the barriers to adopting the control packages discussed (MDA, Vaccine + OXF and Health education)? How can the barriers be overcome?

Appendix 5:Ethical approval letter

ILRI INTERNATIONAL LIVESTOCK RESEARCH INSTITUTE

CGIAR

26th June 2019

Our Ref: ILRI-IREC2019-20

International Livestock Research Institute
P.O. Box 30709 00100
Nairobi, Kenya.

Dear Kristina Roesel, PhD & Nicholas Ngwili

Ref: Designing integrated strategies for the control of Taenia Solium infections in Uganda

Thank you for submitting your request for ethical approval to the International Livestock Research Institute (ILRI) Institutional Research Ethics Committee (IREC). ILRI IREC is accredited by the National Commission for Science, Technology and Innovation (NACOSTI) in Kenya, and approved by the Federalwide Assurance (FWA) for the Protection of Human Subjects in the United States of America.

This is to inform you that ILRI IREC has reviewed and approved your study titled *'Designing integrated strategies for the control of Taenia Solium infections in Uganda'*. The approval period is 26th June 2019 to 25th June 2020 and is subject to the following requirements:

Appendix 6: Research permit

Uganda National Council for Science and Technology

(Established by Act of Parliament of the Republic of Uganda)

UNCST

Our Ref: A 606

9th September 2019

Mr. Nicholus Musyoki Ngwili
Principal Investigator
International Livestock Research Institute
Kampala

Dear Mr. Ngwili,

Re: Research Approval: Designing Integrated Strategies for the Control of Taenia Solium Infections in Kamuli and Hoima Districts of Uganda

I am pleased to inform you that on **27/8/2019**, the Uganda National Council for Science and Technology (UNCST) approved the above referenced research project. The Approval of the research project is for the period of **27/08/2019** to **27/08/2020.**

Appendix 7: Consent form for household survey

Household survey informed consent form

Name of Principal Investigator: Nicholas Ngwili

Organization: International Livestock Research Institute

[Please leave a copy of this form with the participant]

Information about the study

You are being requested to participate in a research study. The study is led by the International Livestock Research Institute office in Uganda and Makerere University, Uganda. The project is funded by CGIAR research program on Agriculture for Nutrition and Health (A4NH). I will now give you a brief explanation of what participating in the study involves so that you can decide if you want to participate.

This research project is trying to obtain information on pig farming specifically information on how you keep your pigs including housing, feeding and treatment. We will also be interested in knowing how you observe household hygiene and how the household protects its members against worm infections. We will be interviewing 200 households, 100 in Kamuli and 100 in Hoima district that have been randomly selected. If you agree to participate, we will ask you to answer a few questions about your household, the pig keeping practices, household hygiene and pork consumption in the household. We will also be requesting you to allow us take blood and Fecal samples to check for *Taenia solium* infection and gastrointestinal worms respectivelyfrom up to 3 pigs in your farm. We will also get a sample of faecal matter from the ground where your pigs stay. The interview will take between 45 minutes and up to 1 hour.

Blood and faecal sampling: On blood sampling, the pig will be restrained standing, using a pig snare, blood samples will be taken from the anterior vena cava on the pig's right side using the BD Vacutainer needle and tube by a veterinary technician. A single BD Vacutainer® 10-ml plain tube and single BD Vacutainer® 4ml EDTA tube identified with unique barcodes will be collected. While pigs are restrained using the standard pig snare for blood sampling, a rectal fecal sample will be collected digitally using a figure with gloves on before it is released

Participation in this study is entirely voluntary: Participation is voluntary, refusal to participate will not result in a penalty or a loss of benefits to which you are otherwise entitled, and you may discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled.

Confidentiality: Confidential information concerning the study participants will not be shared. The research team promises to respect your privacy and confidentiality. We will not tell anyone that you participated in this interview and a study number rather than your name will be used on study records. Your name will be deleted from all the documents that contain data, so that no one can link the data to your name. Information that will be obtained from the blood sample and questionnaire will be kept confidential. This information will be stored in a password protected server and only the researchers will access this information.

Benefits from the study: We will not compensate you for your time and participation, but we appreciate your participation. Part of the results of the study will be shared during planned stakeholder workshop later in the course of the study before its later shared with the general public through scientific communication. We hope the information we will obtain from this study will help us understand the risks of exposure to worm infection including *Taenia solium* and help us propose intervention strategies against the parasite. This will not only benefit Uganda but the entire East Africa.

Risks of participating in the study

There are no foreseeable risks associated with participating in this study but if you feel uncomfortable, you can end the interviews at any time. There is low risk to pigs due to blood sampling which will be done by trained and registered veterinarians, but in case of complications the attending vet will assess and treat, or if the project staff have left the premises, the local vet will be called to assess and treat. In case of death directly associated with sampling the farmer will be compensated at the prevailing market price of the animal.

This proposal has been reviewed and approved by the Research Ethics Committee (REC) at College of Veterinary Medicine, Animal Resources and Biosecurity, Makerere University.

If you agree to be in the study but change your mind later, that is still OK; you can stop any time. If you have any question, please feel free to ask before we proceed.

Will you be a part of this study? ☐ Yes ☐ No

Informed consent

"I consent to participate in the *Taenia solium* study. I have read or the information has been explained to me and I have understood the information presented in this document and have been given the opportunity to ask questions"

Name of the participant________________________ Signature________________ Thumb print

Date __________________________

Name of witness_________________________ Signature____________________ Thumb print

Date_____________________________

Name of the researcher _______________________ signature _________________ Thumb print

Date ______________________

If you have any further questions or have any concerns about the study, please contact:

The researcher: Nicholas Ngwili +254710294613/n.ngwili@cgiar.org or Peter Lule +256 759 127931

Appendix 8:Consent form for qualitative survey

***Taenia solium* control project**

Informed Consent for Focus Group Discussions/Key informant interviews

Good morning/afternoon, I am ____ from the International Livestock Research Institute (ILRI). The International Livestock Research Institute office in Uganda and Makerere University, Uganda is carrying a study to help design integrated strategies to control Taenia solium infections in Uganda. Specifically, we aim to use participatory methodologies to understand the context, barriers and opportunities for the control of *Taenia solium* infections in Kamuli and Hoima districts, Uganda. The project is funded by CGIAR research program on Agriculture for Nutrition and Health (A4NH). To find answers to these questions, we are holding focus group discussions or key informant interviews, about an hour long, with community members and other stakeholders to obtain their feedback and inputs. The entire discussion will be tape-recorded, and notes will also be taken. The audio files and notes are considered confidential, and no one else except the research team will have access to them. Once we are through with these materials, we will discard them through means that guarantee confidentiality. The reports generated from these data will also uphold discussants' confidentiality. Participating in this discussion is voluntary and choosing to withdraw will not affect you or your relationship with our organisation in any way. You are free also not to answer any question that makes you uncomfortable. However, your full participation is likely to help us make better decisions concerning management and control of *Taenia solium* infections. If you wish to find out more about this project, contact the researcher: Nicholas Ngwili - +254710294613

Discussant's declaration: "I have read the foregoing information, or it has been read to me. I have had the opportunity to ask questions about it and any questions I had have been answered to my satisfaction. I consent voluntarily to participate in this study and understand that I have the right to withdraw from the discussion at any time with no consequences."

Researcher's Name___________________________________Signature_________________

Date _________________________________

Participant's Name___________________________________Signature________________

Date __________________________________**Thumb print**

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Title: FACTORS AFFECTING THE DESIGN OF INTEGRATED STRATEGIES FOR THE CONTROL OF *TAENIA SOLIUM* INFECTIONS IN KAMULI AND HOIMA DISTRICTS, UGANDA.

Author: NGWILI NICHOLAS MUSYOKI

Depositor's Declaration

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Name; Ngwili, Nicholas Musyoki

College; College of Agriculture and Veterinary Sciences

Sign;

Date; 18/02/2022