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Prevalence of porcine cysticercosis and associated risk factors in smallholder pig production systems in Mbeya region, southern highlands of Tanzania

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ABSTRACT

Porcine cysticercosis (PC) caused by the larval stage of a zoonotic tapeworm *Taenia solium*, is known to pose serious economic losses and public health risk among smallholder pig production communities. The present study was conducted to determine prevalence and associated risk factors for PC in smallholder pig production systems in Mbeya region, the major pig rearing region of Tanzania. A cross-sectional survey employing a random sample of 300 pig keepers from 30 villages of Mbozi and Mbeya Rural districts, Mbeya region were used to evaluate pig production systems and practices. Concurrently, 600 male and female pigs of different age categories were randomly selected and examined for PC using lingual examination method and antigen enzyme-linked immunosorbent assay (Ag-ELISA). The overall pig level PC prevalence in Mbozi district was 11.7% (95% CI = 8.5–15.8%) and 32% (95% CI: 27–37.5%) based on lingual examination and Ag-ELISA, respectively. In Mbeya Rural district, the prevalences were 6% (95% CI: 3.8–9.3%) and 30.7% (95% CI: 25.8–36.1%) by lingual examination and Ag-ELISA, respectively. In Mbozi district 46% of the households were found infected (one or more infected pigs) and the corresponding figure was 45% for Mbeya Rural district. The agreement between lingual examination and Ag-ELISA was poor ($\kappa < 0.40$). There were no significant differences in the prevalence of PC in different sex categories of pigs. Significant risk factors associated with PC prevalence were free roaming of pigs (OR = 2.1; 95% CI = 1.3–3.6; $p = 0.006$), past experience of porcine cysticercosis in the household (OR = 2.6; 95% CI = 1.5–4.8; $p = 0.002$), increased age of pig (OR = 1.9; 95% CI = 1.2–3.0), slatted raised floor in pig pen (OR = 8.4; 95% CI = 1.0–70.0), in-house origin of the pig (OR = 1.6; 95% CI = 1.1–2.5) and sourcing of water from rivers (OR = 3.1; 95% CI = 1.6–6.3; $p < 0.001$) and ponds (OR = 5.0; 95% CI = 1.2–21.7; $p = 0.031$). This study has clearly revealed a high sero-prevalence of PC in the study area, which imposes a major economical and public health burden to the smallholder pig farmers. The study also points to a number of important risk factors in smallholder pig management that may be addressed (e.g. confinement, quality of pens and water sources) in future interventions and educational campaigns for control of *T. solium*.

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1. Introduction

Pig production in Tanzania is one of the fastest growing livestock sub-sectors involving over 7% of the smallholder farmers and 18% of livestock keeping households, based on low input–output management systems (URT, United Republic of Tanzania, 2006; FAOSTAT, 2009). The farmers have consistently increased the supply of pork, thus, increased availability and consumption of animal protein in rural and urban families. The predominance of smallholder production systems in the sub-sector and associated poor husbandry and limited biosecurity does, however, make it vulnerable to diseases, like African swine fever, and food safety threats, particularly porcine cysticercosis (PC). PC is an infection in pigs with the larval stage of the tapeworm *Taenia solium* (cysticercosis). It is an important parasitic zoonosis with humans harbouring the adult stage of the parasite (taeniosis). Human infection results from ingestion of infected pork, whereas pigs get infected by consuming human faeces or feed/water contaminated with taeniid eggs from humans. Occasionally humans ingest *T. solium* eggs, which develop into cysts in different body tissues with serious consequences resulting from cysts in the central nervous system, a condition termed as neurocysticercosis (NCC). PC is most prevalent in rural pig keeping communities of developing countries, Tanzania inclusive (Perry et al., 2002; Phiri et al., 2003; Zoli et al., 2003; Ngowi et al., 2004a; Boa et al., 2006). The disease has, since the first finding in a slaughter slab in Mbulu district in 1985 (Nsengwa, 1995), been reported as an emerging and increasing problem in smallholder production systems throughout the country (Boa et al., 1995). Subsequent studies based on ante-mortem lingual examination established prevalence in the Northern highlands (Ngowi et al., 2004a) and Southern highlands of Tanzania (Boa et al., 2006). It is however important to note that lingual examination method can detect only about 21% of truly infected pigs (Dorny et al., 2004). The disease has become a major barrier to local, regional and international trading of pigs and pork. Smallholder pig keepers have become the most vulnerable group along the pig production and marketing chain; both to income loss when their pig assets cannot be sold or are condemned at slaughter due to PC, and also when their lives are prone to *T. solium* taeniosis and cysticercosis. *T. solium* infections are, however, not limited to the rural pig producers but are also extended to urban pork consumers to whom the rural pig producers are among the suppliers (Mkupasi et al., 2011).

The need for controlling PC is fundamental for improving smallholder pig production, safe pork consumption and improvements in public health both in Tanzania and other PC endemic countries in Africa. However, lack of information on the PC prevalence and associated risk factors in the local setting has been an important limiting factor to that effect. Therefore, the current study was conducted in Mbozi and Mbeya Rural districts with the largest pig populations in the country, to determine the prevalence of PC and associated risk factors in order to provide inputs necessary for developing sustainable control strategies.

2. Materials and methods

2.1. Ethics statement

The study protocol was approved by the Postgraduate Studies Committee of the Faculty of Veterinary Medicine, Sokoine University of Agriculture, which is an institutional review board for studies related to the field of Veterinary Medicine and Public Health. The Committee approved obtaining verbal consents from pig farmers for their participation in the survey and allowing involving their pigs in the study. Verbal consents were purposely adopted as some respondents could not read or write. Sampling of blood from pigs was performed by qualified registered veterinarians. Following completion of the study feedback seminars were conducted in the study villages, which also involved training of the rural farmers on possible control measures of the disease.

2.2. Study area

This study was conducted in Mbozi and Mbeya Rural districts located in Mbeya region in southern highlands of Tanzania. The temperature in Mbeya region ranges between −6 °C in the highlands and 29 °C in the lowlands. Average rainfall per year is around 900 mm. The rainy season is from November to May with heaviest rainfall occurring during the months of December to March. Mbeya Rural district lies between latitudes 8° 38′ and 9° 20′ S and longitudes 33° 01′ and 33° 49′ E. It has 126 villages (URT, 1997), covering a total area of 2334 km^2 and 254,069 inhabitants (NBS, National Bureau of Statistics, 2003). In 2002 the district had a pig population of 33,535 (URT, 2006). Mbozi district is located in the south-western corner of Mbeya Region. It lies between latitudes 8°14′ and 9°24′ S and longitudes 32° 04′ and 33° 13′ E. It comprises of 152 villages (URT, 1997), covering a total of 9586 km^2 and 513,600 inhabitants (NBS, 2003). In 2006 it had a pig population of 57,898 (URT, 2006).

2.3. Study design and sample size

A cross-sectional survey was conducted between November 2007 and January 2008. A multistage sampling technique was used to sample villages, households (HH), and pigs. Sample size for HH was calculated based on formula by Bartlett et al. (2001). A total of 300 HH were involved (150 per district). In each district the households were picked from 15 randomly selected villages from lists of all pig keeping villages in the district (10 pig keepers' HH per village). An estimation of the sample size of the pigs required for the study was based on the formula by Martin et al. (1987), in which 300 pigs were examined in each of the two districts. In households with one or two pigs, all the pigs were examined while in households with more than two pigs; a proportion of the pigs were randomly selected for sampling. Sows that had recently farrowed or were in late pregnancy, and piglets less than two months old were excluded from the study.

2.4. Household questionnaire and direct observation

Data at household level were collected using structured questionnaire and standardised observations. The targeted respondents were the household heads, though in their absence other family members who could deliver the required information were interviewed. Data collected included household demographic variables, pig management systems and practises, awareness and knowledge of PC, experience of PC in the pig herd and hygienic factors such as latrine use and water assess and sanitation. Direct observations were further used to assess hygiene and sanitary practices, including availability and conditions of toilets.

2.5. Determination of porcine cysticercosis in study pigs

Examined pigs were categorised as weaners (2–4 months old), growers (5–8 months old), or adults (≥9 months). They were subjected to ante-mortem lingual examination, and blood was collected from either the external jugular vein or the cranial vena cava adopting a method previously described (Pondja et al., 2010, 2012). The clotted blood samples were centrifuged to obtain serum, which were stored in Eppendorf tubes at −21 °C until analysis. A pig was considered positive by lingual examination if cysts were seen or felt in the tongue as described by Gonzalez et al. (1990). An ELISA detecting circulating *T. solium* antigens (Ag-ELISA) was performed using the monoclonal antibody B158/B60 as described by Brandt et al. (1992) and modified by Dorny et al. (2004).

2.6. Statistical analysis

Data on pig infections and risk factors were entered and analysed using Stata 10 (Stata Corp., College Station, Texas 77845 USA, 2007). A multivariate logistic regression analysis was performed to obtain odds ratios and 95% confidence intervals of risk factors for seropositivity to porcine cysticercosis both at pig ($N = 600$) and HH ($N = 300$) levels. Agreement between lingual examination and Ag-ELISA was determined using Kappa statistic. In this study, a HH was considered PC positive when at least one pig in the HH was found infected using Ag-ELISA.

3. Results

3.1. Prevalence of porcine cysticercosis

Of the 600 examined pigs, 151 were weaners, 125 growers and 324 adults. Almost 97% of the pigs were of the indigenous breeds with 64% being females. The overall pig prevalence of PC in Mbozi district was 11.7% (95% CI = 8.5–15.8%) by lingual examination and 32.0% (95% CI = 27.0–37.5%) by Ag-ELISA. Mbeya Rural district had an overall prevalence of 6.0% (95% CI = 3.8–9.3%) by lingual examination, and 30.7% (95% CI = 25.8–36.1%) by Ag-ELISA. In both districts PC prevalence levels by the two methods were significantly different ($p < 0.0001$), and there was poor agreement between the two methods (Mbozi district $\kappa = 0.39$ (CI = 0.32–0.46), Chi-square = 35.0; $p < 0.0001$; Mbeya Rural district $\kappa = 0.25$ (CI = 0.19–0.31); Chi-square = 59.4; $p < 0.0001$). The differences in prevalence between the two districts by the same method were not statistically significant ($p > 0.05$).The prevalence of PC in pigs varied between villages. In Mbozi district, the PC prevalence in all pigs sampled at village level ranged between 5% and 25% by lingual examination and 5–50% by Ag-ELISA, and consequently all villages were found infected. In Mbeya Rural, the village level prevalence range was 0–20% and 5–60% by lingual examination and Ag-ELISA, respectively. In both districts, the proportion of PC (Ag-ELISA) infected households ranged between 10% and 90% per study village. In Mbozi district 46% of the households were found infected and the corresponding figure was 45% for Mbeya Rural district. Mbozi district had 53% of villages having half or more of their households infected, where as 47% of villages in Mbeya rural district had half or more of their households infected.

3.2. Questionnaire survey results

A total of 193 men and 107 women were interviewed in the 300 households. Their ages ranged from 20 to 90 years. The levels of education of the respondents were such that 72% had primary school education, 6% secondary school education, 4% adult education, 1% had college/university education and 16% had no formal education. All the visited pig keepers practiced mixed farming, i.e. a combination of livestock species, typically pigs; and cash (coffee) and food (maize) crops production. A few of the respondents were in addition employed in paid jobs or other businesses. Forty two percent of the pig farmers practiced total confinement whereby pigs were confined throughout the year. Confined pigs were mainly fed maize bran, grass, brewer's waste, household kitchen waste; and banana and sweet potatoes leaves. The remaining proportion of interviewed farmers practiced either semi-confinement or free-range management systems. In semi-confinement management system, pigs were partially confined in the shelters or tethered depending on the period of day and/or season, while in the free-range management systems pigs were allowed to roam freely and/or herded in most of the period of the year. Some farmers (13%) slaughtered pigs at home, and almost all (99%) did it without inspection. Forty six percent of the visited households accessed water from surface sources (springs, ponds, and rivers) and the rest got water from taps and boreholes. Latrines were present in 94% of the pig keepers' households in the study area but most (over 90%) did not have closing doors. Presence of human faeces on the toilet floor was a common phenomenon and these could easily be accessible by scavenging pigs and escaping piglets. Majority (93%) of the pig keepers were aware of PC in pigs but only a small proportion (23%) knew how pigs get infected. Consequently, only 14% of the respondents had knowledge about the epidemiological link between the disease in pigs and human infections. Increased level of education significantly increased the knowledge on PC and its zoonotic potential ($p < 0.05$), and pig keepers in Mbeya Rural district generally had better knowledge than their counterparts in Mbozi district (OR = 2.0, $p = 0.018$). Twenty

Table 1
Multivariate logistic regression analysis of intrinsic pig factors associated with porcine cysticercosis (PC) in 600 pigs examined by Ag-ELISA (B158/B60) in Mbozi and Mbeya Rural districts, Tanzania.

Factor	Level	*n*	PC +ve (%)	Odds ratio (95% CI)	*p*-Value
Age class	Weaner (2–4 mths)	151	25.3	1.0 (ref)	–
	Grower (5–8 mths)	125	25.6	1.1 (0.7;2.0)	0.63
	Adult (≥9 mths)	324	36.1	1.9 (1.2;3.0)	0.009**
Sex	Male	214	31.8	1.0 (ref)	–
	Female	386	30.9	0.8 (0.6;1.2)	0.34
Pig origin	HH within village	170	24.7	1.0 (ref)	
	HH outside village	95	28.7	1.2 (0.7;2.0)	0.63
	Within HH	335	35.2	1.6 (1.1;2.5)	0.026*
District	Mbozi	300	32.1	1.0 (ref)	
	Mbeya rural	300	30.3	1.0 (0.7;1.5)	0.84

n, number of households.
* Significant ($p < 0.05$).
** Significant ($p < 0.01$).

two percent of pig keepers had experienced PC infection in their herds, with no significant difference between these two districts ($p > 0.05$). Most of PC infected pigs were identified by pig traders during marketing process using lingual inspection. Eighty two percent of pig keepers ate pork at least once a month.

3.3. Risk factors for porcine cysticercosis in the study area

The factors that were considered in the multivariate logistic regression analysis as risks associated with PC included intrinsic factors of the pig, i.e. age, sex and pig origin (Table 1); and extrinsic factors which included HH demographic factors (marital status, education level, gender, and age of household head), pig management systems, water source and distance to water source, types of pig shelters, pig shelter quality (strong, moderate and weak), latrine (presence/absence) and its condition/cleanliness, past experience of PC in the pig herd, consumption of pork, home slaughter of pigs, knowledge on PC and pig keeping experience. At pig level, only age and origin of the pig were found significant in the logistic regression model as older pigs (≥9 months) were more often infected than younger (OR = 1.9), and pigs raised within the HH had a higher risk of being infected than pigs bought from outside the HH (OR = 1.6) (Table 1). Considering other factors in the multivariate logistic regression model at HH level, only the following were significantly associated with PC: pig management system, floor of the pig shelter, past experience of PC in the pig herd, and source of water for pigs (Table 2). Briefly, the risk of PC sero-positivity (Ag-ELISA) in a HH was significantly increased in free-range and semi-confinement husbandry systems as compared to total confinement, slatted raised floor type of pig shelter in contrast to concrete floor, sourcing water from rivers and ponds in contrast to tap water, and in HH with past experience of PC in the pig herd (Table 2). By using back elimination in a multivariate logistic model in which all factors were initially included, good predictors of PC were identified (specified at probability = 0.1) and listed with resulting ORs (Table 3).

4. Discussion

The present study reports the magnitude and associated risk factors for PC in southern highlands of Tanzania. It has clearly revealed that based on large-scale sampling, PC is highly endemic (>30% sero-prevalence) and distributed throughout in the study area. The study supports and explains findings in the human population in the same region, having a prevalence of *T. solium* cysticercosis based also on circulating antigens of 16.7% and of taeniosis of 4.1%, based on a combination of copro-Ag-ELISA and circulating antibodies (Mwanjali et al., 2013). The finding thus implies a great public health risk not only to these rural areas where pigs are produced, but also to urban centres where pigs from rural areas are eventually transported (Sikasunge et al., 2007; Mkupasi et al., 2011). These urban centres are featured by large populations with high demand for pork. Furthermore, the migration of tapeworm carriers from rural areas to the cities poses a higher transmission risk of cysticercosis when poor environmental and social conditions are present (Sarti et al., 1992).

The present study employed two different techniques to detect PC infection in live pigs, i.e. a conventionally used technique (lingual examination) and a serological technique (Ag-ELISA). The observed levels of PC infection by lingual examination in this study are comparable to those obtained previously by researchers in other parts of southern highlands (Boa et al., 2006) but lower than those obtained in the northern part of the country (Ngowi et al., 2004a). The method, known to be quick and inexpensive, has however been found to have low and variable sensitivity in detecting PC. In Peru, Gonzalez et al. (1990) observed that the test could detect up to 70% of infected pigs ($n = 53$) as compared to necropsy (gold standard); whereas a study in Zambia by Phiri et al. (2006) reported that lingual examination could detect 61.3% of *T. solium* infected pigs ($n = 65$). In both studies the technique exhibited a high specificity of 100% (Gonzalez et al., 1990; Phiri et al., 2006). With same specificity, another study in Zambia followed by Bayesian analysis of data found that lingual examination could only detect 21% of truly infected pigs while the sensitivity of

Table 2
Multivariate logistic regression analysis of management practices, hygienic and other selected risk factors associated with households (HH) being positive for porcine cysticercosis (PC) in Mbozi and Mbeya Rural districts, Tanzania ($N = 300$).

Factor	Level	*n*	PC +ve HH (%)	Odds ratio (95% CI)	*p*-Value
Pig management system	TC	126	35.7	1.0 (ref)	
	SC and FRH	174	52.3	1.8 (1.0;3.3)	0.039*
Type of floor in pig shelter	Concrete	13	7.7	1.0 (ref)	
	Earthed	130	46.7	6.7 (0.8;59.7)	0.086
	Slatted (raised)	142	48.6	9.1 (1.0;78.4)	0.045*
Pork use by pig keepers	No	36	52.8	1.0 (ref)	
	Yes	262	44.7	0.4 (0.2;1.1)	0.08
Past experience of PC in the pig herd	No	204	39.7	1.0 (ref)	
	Yes	64	62.5	2.2 (1.1;4.4)	0.032*
	Do not know	28	42.9	1.2 (0.5;3.0)	0.72
Presence of latrine	Yes	281	44.5	1.0 (ref)	
	No	18	61.1	1.96 (0.7;5.2)	0.18
Presence of faeces around latrine/homestead	No	225	44.4	1.0 (ref)	
	Yes	57	43.9	0.8 (0.4;1.5)	0.45
Source of water	Tap water	61	32.8	1.0 (ref)	
	Borehole	100	40.0	1.5 (0.7;3.4)	0.31
	Spring	28	35.7	0.8 (0.2;2.7)	0.72
	River	98	60.2	3.3 (1.5;7.6)	0.005**
	Ponds	11	63.6	6.6 (1.2;36.3)	0.029*

TC, total confinement; SC, semi-confinement; FRH, free range husbandry; *n*, number of households.
* Significant ($p < 0.05$).
** Significant ($p < 0.01$).

Ag-ELISA was 86.7% (Dorny et al., 2004). Although effects related to the experience and exact method employed by the examiner cannot be ruled out, the latter study might be more reliable as the Bayesian analysis takes into consideration that neither of the tests under comparison is perfect. It has been argued that not all infected pigs necessarily have cysts on their tongues and it is likely that infection intensity is the most important factor determining whether cysts are discernible by visual inspection of the tongue or not (Sarti et al., 1992). It is thus not surprising that in the present study Ag-ELISA detected 3–5 times more cases than lingual examination method, supporting studies elsewhere (Pouedet et al., 2002; Nguekam et al., 2003; Sikasunge et al., 2008; Pondja et al., 2010). The monoclonal antibodies used in the Ag-ELISA were originally raised against a *Taenia saginata*-cyst excretory/secretory antigen (Brandt et al., 1992). Due to strong cross-reactivity to *T. solium*, the test has shown good diagnostic characteristics in PC based on Bayesian analysis, as mentioned above (Dorny et al., 2004), and has produced meaningful results in pig populations in South Africa, Zambia, and Mozambique (Krecek et al., 2008; Sikasunge et al., 2008; Pondja et al., 2010). The antibodies are, however, genus-and not species-specific, and the Ag-ELISA has a problem of cross-reactions with *Taenia hydatigena* (Cheng and Ko, 1991; Dorny et al., 2004) and potentially other cestodes. But *T. hydatigena* is to our knowledge not common in pigs in the African context with prevalences at necropsy of 6.7%, 6.1% and 1.4% in Ghana, Zambia, and Tanzania, respectively (Permin et al., 1999; Dorny et al., 2004; Ngowi et al., 2004b). Although the prevalence of *T. hydatigena* in pigs in the specific study area is unknown and other cross-reactions may occur, these are likely to account for only a small proportion of the measured PC sero-prevalence.

Free range pig and semi-confinement management system was identified as an important risk factor for PC in both districts. The system exposes the roaming pigs to *T. solium* eggs as they can easily access human faeces from *T. solium* carrier humans. Other studies elsewhere within Africa (Sikasunge et al., 2007; Krecek et al., 2008; Waiswa et al., 2009; Pondja et al., 2010) and Latin America (Sarti et al., 1997; Sakai et al., 2001) also identified extensive pig management system as an important risk factor for transmission of *T. solium* eggs to pigs. The system, when coupled

Table 3
Identification of good predictors for porcine cysticercosis (PC) at household level based on backward elimination (if $p > 0.1$) in a multivariate logistic model. The table specifies the final model.

Factor	Odds ratio (95% CI)	Standard error	*p*-Level
Earthed floor	6.8 (0.81–56.40)	7.3	0.077
Slatted raised floor	9.3 (1.15–76.24)	10.0	0.037
SC & FRH pig management systems	2.0 (1.12–3.44)	0.6	0.018
Previous experienced PC infection in pig herd	2.0 (1.02–3.74)	0.6	0.044
Sourcing water from river	2.9 (1.62–5.10)	0.8	0.000
Sourcing water from ponds	4.7 (1.00–22.31)	3.7	0.050

SC, semi-confinement; FRH, free range husbandry.

with feeding behaviour of pigs (i.e. pig is a natural scavenger of faeces) and open human defecation, provides a good background for pigs to access human faeces with *T. solium* eggs.

In many endemic areas the prevalence of porcine cysticercosis is increasing with increasing age of the pigs (Sarti et al., 1992; Pouedet et al., 2002; Garcia et al., 2003; Copado et al., 2004; Elahi et al., 2006; Morales et al., 2008; Pondja et al., 2010), and the highest prevalence in oldest animals in our study is in agreement with these reports. This may possibly be due to the fact that infection is accidental and older animals might have had longer exposure than the younger ones (Pondja et al., 2010). The demonstrated less risk of PC in younger pigs may also be an attribute of their more sedentary behaviour (Morales et al., 2008), passive transfer of maternal immunity (Elahi et al., 2006) or because they are disadvantaged in the competition to forage when roaming freely (Copado et al., 2004). Maternal antibodies are also known to be protective for other larval cestode infections (Gemmell, 1999) and have been shown to slowly decrease in piglets born to cysticercosis infected sows (Gonzalez et al., 1999). An increase in PC prevalence with increasing age of the pigs was, however not reported in other studies (Ngowi et al., 2004a; Sakai et al., 1998).

Previous experience of PC infection in pig herd in the household and raising pigs originating from the same household were also identified as risk factors for PC prevalence. This observation reflects clustering of infection and denotes the existence of attribute(s) in these households, which enhance the transmission of *T. solium* eggs to pigs. Inadequate hygiene, poor husbandry practices and existence of human tapeworm carriers are suggested to be among important attributes that might have contributed to this observation. While inadequate hygiene and poor husbandry practices provide platform for pigs' access to *T. solium* eggs contaminated faecal matter, human tapeworm carriers are responsible for environmental contamination with *T. solium* eggs and proglottids, which facilitate transmission of both porcine and human cysticercosis particularly when personal hygiene is poor (Garcia-Garcia et al., 1999; Zoli et al., 2003; Lescano et al., 2007; Cortez Alcobedes et al., 2010).

Lack of, and inadequate utilisation of sanitary facilities and services such as latrine and safe water have been shown as primary causes of *T. solium* cysticercosis and taeniosis particularly in PC endemic areas (Silva-Vergara et al., 1998; Gonzalez et al., 2003; Murrell, 2005; Pawlowski et al., 2005; Lescano et al., 2007; Prasad et al., 2009). In our study area, majority of pig-keepers' households had latrines. PC prevalence in households with and without latrines were however statistically similar. This could be attributable to the observed fact that most of latrines were without closing doors and were featured by presence of faeces on the floor which could easily be accessed by roaming pigs and escaping piglets. But also free roaming pigs regardless of their proprietors' latrine ownership status could scavenge indiscriminately across households with and without latrines and thus provide equal chances of being infected. Lack of routine use of latrines could also be thought of although it was not investigated in this study. Similar observations were reported in Mozambique (Pondja et al., 2010), Mexico (Sarti et al., 1992) and West Cameroon (Pouedet et al., 2002). This observation was, however, contrary to results reported by others elsewhere within the country (Ngowi et al., 2004a) and in Kenya (Kagira et al., 2010; Mutua et al., 2007), where the absence of latrine in pig keepers' households was identified as an important risk factor for PC.

Sourcing of water from rivers and ponds were revealed to be important risk factors for PC sero-prevalence in the two study districts. This similar finding was reported in Bahia State, North Eastern Brazil (Sakai et al., 2001). This observation suggests that, *T. solium* eggs contaminate these alternative water sources and pigs get the eggs when provided drinking water from such sources. This needs to be considered if total confinement is promoted. Contamination of rivers and ponds in this area could have been caused by open human defecation followed by convey of the *T. solium* eggs containing faeces by run off to these water sources. Use of unsafe sources of drinking water such as stagnant, surface water from streams, ponds, or uncovered shallow wells as opposed to safe sources, was also found to be a risk factor for exposure to *T. solium* in humans, as measured by antibodies (Mwanjali et al., 2013). The eggs are believed to have an ability of surviving in stagnant and flowing water for a relatively long period of time (Jubb et al., 1992). This observation linking water sources and PC sero-prevalence could, however, be confounded by the fact that most poor households had only access to these surface water sources and they were also the ones featured by other factors such as poor pig husbandry and poor hygienic conditions, so their pigs were more prone to infection. This alternative school of thought can be partly supported by a finding by Diaz et al. (1992) who failed to find eggs in river water samples in a highly endemic community.

Some researchers have associated parasite infections in swine with the conditions of their pens (Fujiwara et al., 1985; Kano and Makiya, 2001; Matsubayashi et al., 2009). In the present study, the prevalence of PC infection in the examined pigs was significantly higher in those kept in shelters with slatted floors. This observation might have been caused by poor condition of those types of structures that allowed escape of pigs from these shelters. Inadequate knowledge of pig keepers on how to prepare appropriate pig structures especially slatted raised floor type of pig shelters might have contributed to this observation. Majority of pig structures of this type were in poor condition, which allowed escape of pigs. Poor pig shelters in smallholders pig-farming systems have also been reported elsewhere as practical limitation in pig husbandry (Lekule and Kyvsgaard, 2003; Phiri et al., 2003; Ajala et al., 2007; Kagira et al., 2010).

5. Conclusion

This study has revealed clearly that PC, based on the present serological test, is highly prevalent in the study area and without doubt imposes a major economical and public health burden to the smallholder pig farmers. Further studies are needed to confirm this high prevalence by other means. The results of the study suggest the existence of *T. solium* human carriers in the study area as they are the only known natural source of PC to pigs. This has recently been confirmed by Mwanjali et al. (2013). The study also points to a number of important risk factors in smallholder pig management that may be addressed (e.g. confinement, quality of pens and water sources) in future interventions and educational campaigns. How these approaches of improved pig management are integrated with meat inspection, targeted use of anthelmintics or vaccinations, and not least control of human infections, in a cost-effective manner need to be investigated in future studies.

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