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RESEARCH

Nexus between prevalence of *Taenia solium* (*Cysticercus cellulosae*) in pigs and retrospective study of humans cysticercosis cases in Benin hospitals

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Abstract
The cysticercosis is a major zoonotic disease in many developing countries. This study was carried out to determine the prevalence of porcine cysticercosis and to identify potential risk factors associated and their seroprevalence as well in Benin. The tongue palpation was performed on 4150 pigs from the pig farmers were randomly selected to diagnose cysticercosis and to assess the risk factors associated. In slaughterhouses, 792 pigs were inspected. Serum samples from 460 pigs were tested of the presence of *Taenia solium* cysticercosis using the HP10 antigen-ELISA (Ag-ELISA). A logistic regression model with a 95% confidence interval was used to analyse the main risk factors associated. The tongue palpation revealed a prevalence of 4.79% at the level of slaughterhouses versus 7.82% in the post-mortem inspection. The Ag-ELISA revealed that more than 40% of the pigs were positive. The risk factors identified were the origin area of pigs, the history of cysticercosis in the farms, the presence or absence of a latrine, the pig-farming systems, the age class of pigs and the source of watering. In addition, 34.48% individuals was tested for taenia versus 13.79% for cysticercosis in the hospitals surveyed. Our results showed the major revelation of porcine cysticercosis and its very high level of risk for a public health in all departments of Benin. Therefore, this study suggests the need to continue epidemiological and sociological surveys with a "One Health" approach in order to design and implement effective control measures in this country of high consumption of pigs.

Keywords Cysticercosis · Pigs · Prevalence · Risk factors · Zoonosis · Benin

Introduction

In Benin, pig farming is fairly developed and widespread throughout rural and urban areas of the country (Tassou et al. 2021a). It is both socially and economically important, contributing to the reduction of youth unemployment. It provides households with income that is used for medical care, schooling of children, and food security (Ayssiwede 2004). Apart from some parts of the country where the consumption and rearing of pigs are a taboo due to religious

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considerations, pork meat is highly valued and consumed by the population of Benin. It ranks the 4th in meat production and the 2nd most important imported meat (Dognon et al. 2018; Tassou et al. 2021b). Pigs are raised using two (02) methods that take into account the housing system and/or the control of animal movements: rearing in which animals are kept in closed habitats and free-range characterised by the absence of habitat, where animals are free to roam. Free-range is often the most common type of farming and health risks (cysticercosis) are frequently cited as a reason for economic losses (Tassou et al. 2021a). Therefore, pork meat is an important source of protein and can be a source of cysticerci contamination, especially since the most common form of consumption is the skewer, which is not fully cooked (Tassou et al. 2021b). According to Sciutto et al (2000), porcine cysticercosis is a larval cestodosis with human taeniasis becoming an endemic parasite complex. Cysticercosis is a major problem in poor regions of the world with traditional livestock systems (Rahantamalala et al. 2016). It is the most common cause of epilepsy in Africa and represents a considerable public health burden, affecting more than 50 million people worldwide (WHO 2011). It also causes heavy economic losses, mainly due to partial or total condemnation of pig organs and carcass during post-mortem inspection or costs incurred during sanitation of affected carcass and antiparasitic treatment in pig farms (Porphyre et al. 2015). According to Rasamoelina-Andriamanivo et al (2013), free-ranging pigs combined with human fecal peril are the most important risk factors for the persistence of the *Taenia/Cysticercosis* complex. However, in Benin, cysticercosis is the main cause of organ and pig carcass seizures with significant financial loss that discourages smallholder farmers (Goussanou et al. 2013). Thus, the main constraint in the control of this disease is the widespread clandestine slaughter, which does not take into account the sanitary inspection of slaughtered pigs. This situation increases the risk of transmission of the *Taenia/Cysticercosis* complex between pigs and humans. Therefore, this study was aimed (i) to determine the prevalence of swine cysticercosis in Benin (prevalence by tongue palpation techniques and post-mortem inspection) associated with risk factors for swine cysticercosis in Benin, (ii) to determine the seroprevalence associated with risk factors and finally (iii) to assess the importance attached to the diagnosis of human cysticercosis and teniasis in Benin hospitals and health centers.

Materials and methods

Ethical statement

All experimental animals were approved and conducted according to established animal welfare guidelines by the Human and Animal Ethical Committee of National University of Agriculture (UNA), Benin.

Study area and Animal sampling

The study was carried out from March 2020 to January 2021 in all departements of Benin (Fig. 1).

Pig Farms were randomly selected and based on the acceptance of the livestock developers to participate in the study. The sample size was calculated with the formula (Martin et al. 1987):

$$n = t^2 \times p \times (1 - p)/m^2 \quad (1)$$

where: n is the required sample size for significant results, t = 1,96 is the standard normal deviate at 5% level of significate, p is the estimated prevalence, (1-p) and m is the precision of the estimate. However, a sample size of 119 pigs was required for the study in each department in order to minimize the possibility of chances. In the field, a total of 4150 and 792 pigs were sampled in the farms and slaughterhouses, respectively.

Prevalence of porcine cysticercosis by tongue palpation

The tongue palpation (ante mortem inspection) involves pulling the tongue of the animal to examine its underside where *Taenia solium* can be seen or felt (Eshitera et al. 2012). Its performance requires good restraint and expertise in tongue palpation. This technique has been used to screen live animals from farms and animals for slaughter.

Prevalence of porcine cysticercosis at post-mortem inspection

The post-mortem inspection is a classic meat safety control at the slaughterhouse level. It involves a set of acts that are the assessment of the general condition of the carcass, incisions made on the muscles of the thigh, fillets, muscles of the arms, masseters and tongue in search of cysticerci (Dorny et al. 2004). This was done during this study with the input of the veterinary doctors who are mandated by the government. In both methods, detection of at least one cysticerci provides a positive status on the animal. The absence of a visible cysticerci provides a negative status.

Seroprevalence of porcine cysticercosis

Pigs were immobilized and bled from the anterior vena cava using BDVaccutainer® needles (gauge 19) and BDVacutainer® plain tubes (10 ml). The blood samples of 460 local and crossbred pigs were obtained kept standing in an ice

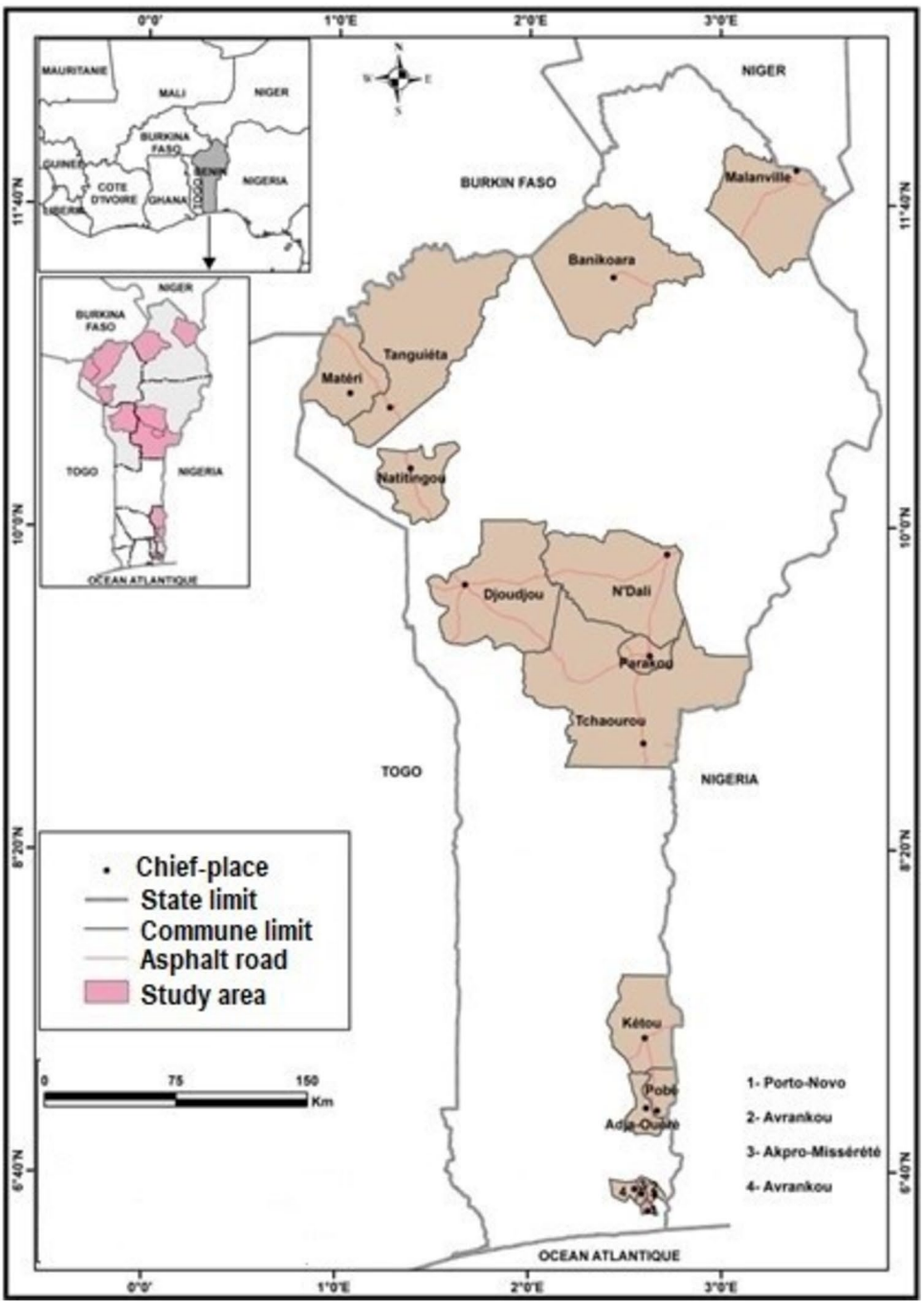

Fig. 1 Cysticercosis prevalence study area

box at + 4 °C to ensure that no hemolysis occurred while in the field. Once in the laboratory, blood samples collected were centrifuged to separate serum from blood clot. Thus, the serum was harvested into barcoded 2 ml vials that were stored at − 20 °C until processing.

The HP10Ag-ELISA was employed for the serological analysis for *T. solium* cysticercosis antigen was carried out at the "Laboratoire Vétérinaire de Bohicon" (LABOVET) of Benin with some modifications described by (Krecek et al. 2008; 2011) and the commercially available B158C11A10/B60H8A4 Ag-ELISA (apDIA Cysticercosis) following the manufacturer's instructions (ApDia n.v, 2004).

The Ag index of each sample was calculated according to the formula (1):

$$\text{Agindex} = \frac{\text{AverageODofthesample}}{\text{DOaverageofnegativecontrol} \times 3.5} \quad (2)$$

The sample considered was: negative if Ag index ≤ 0.8; positive if Ag index ≥ 1.3; and uncertain if $0.8 \leq$ Ag index ≤ 1.3.

Assessment of factors associated with porcine cysticercosis

Direct observations of the farms were made to identify risk factors associated with prevalence of porcine cysticercosis. In addition to parasitological examinations and blood sampling, a cross-sectional survey was carried out by means of a questionnaire to collect information on the identity of the farmer, the sex, age and breed of pigs, farming systems, the hygienic conditions on the farms, the presence or absence of latrines, the pig's exposure to human faeces and the origin of the water and feed given to the pigs.

Retrospective study of human cysticercosis cases in Benin hospitals

The retrospective study of human cysticercosis cases in Benin hospitals was carried out from 2016 to 2020 based on the registers parasitological analysis of twenty-nine (29) hospitals and health centers in Benin (Fig. 2) distributed as follows: thirteen (13) zone hospitals, eight (08) Communal Health Centers, two (02) Departmental Hospital Centers, one (01) Army Hospital, four (04) private clinics and one (01) "Centre National Hospitalier Universitaire" (CNHU) Hubert Koutougou MAGA. The hospitals were selected on the basis of the acceptance of the managers and heads of parasitological services to participate in the study. The study targeted medical data from 2016 to 2020, five (05) years. No patient identity was revealed and only statistical data were obtained. The aim was to analyze, through the statistics of the registers, the importance given to parasitological examinations, especially those related to the *Taenia/Cysticercosis* complex.

Statistical analysis

The data related to tongue palpation were recorded in Excel spreadsheet (Miscrosoft Office 2013). All data were exported in R statistical software version 3.5.2 for analysis.

The data on the age of the animals in the farms and slaughterhouses were coded into three (03) age classes ($0 \leq A < 3$ months; $3 \leq A < 12$ months; $A \geq 12$ months). The logistic regression model allowed us to analyze the effects of age, sex, departement of origin of pigs, and farming systems on the prevalence of porcine cysticercosis at post-mortem inspection and tongue palpation. Odds ratio (OR) allowed us to measure the associations between porcine cysticercosis and potential risk factors and then the chi-square test was used to assess the relationship between them. The significance level was set at $p \leq 0.05$. The results were reported as adjusted odds ratios with 95% confidence intervals (CIs).

The prevalence ***P*** of the different categories of animals was determined with the formula (2) (Pouedet et al. 2002).

$$P = \frac{\text{Number of positive animals}}{\text{Number of animals tested}} \times 100 \quad (3)$$

For the inventory of tapeworm and cysticercosis cases, the data were entered into an Excel spreadsheet and coded as follows. Positive responses were coded as "1" and negative responses as "0". Descriptive statistics (absolute and relative frequencies) of the responses were translated into centesimal proportions and presented in tables and figures.

Results

Prevalence of porcine cysticercosis by tongue palpation

The results of tongue palpation in all departements of Benin were presented in Table 1. The prevalence of porcine cysticercosis was 1.8% versus 4.8% in farms and slaughterhouses, respectively. These prevalence of infestation varied significantly according to departements, breed, sex, age of animals, and farming systems (Table 1).

On tongue palpation, the prevalence of infestation was most frequent in the departements of Borgou and Littoral. The prevalence of infestation was 4.8 and 3.6% respectively. With respect to slaughterhouses, the highest prevalence was recorded in Alibori (15.4%) and Atacora (13.3%). The lowest prevalence was observed in the departement of Couffo (0%), Zou (0.2%) and Donga (0.3%).

According to sex, a significant difference ($p < 0.05$) was observed between the prevalence of infestation obtained in the farms and slaughterhouses. Porcine cysticercosis was slightly higher in local pigs (2.1%) than in crossbred pigs (1.3%). In slaughterhouses, the prevalence was significantly higher in local pigs (6.6%) while no cases were observed in crossbred breeds. Of the 1714 males and 2436 females examined in the farms, 32 males (1.9%) and 42 females (1.7%) were positive for porcine cysticercosis. But, in slaughterhouses, of the 319 males and 473 females examined, 18 males (5.6%) and 20 females (4.2%) were examined positive by tongue palpation.

According to age, the results showed a significant ($p < 0.05$) prevalence at tongue palpation (3.7%) in adult pigs (age greater than 12 months) than in younger ones. A lowest proportion (0.53%) was observed in pigs aged 0 to 3 months. A significant difference ($p < 0.05$) was also found between the prevalence obtained by the age of the pigs examined in

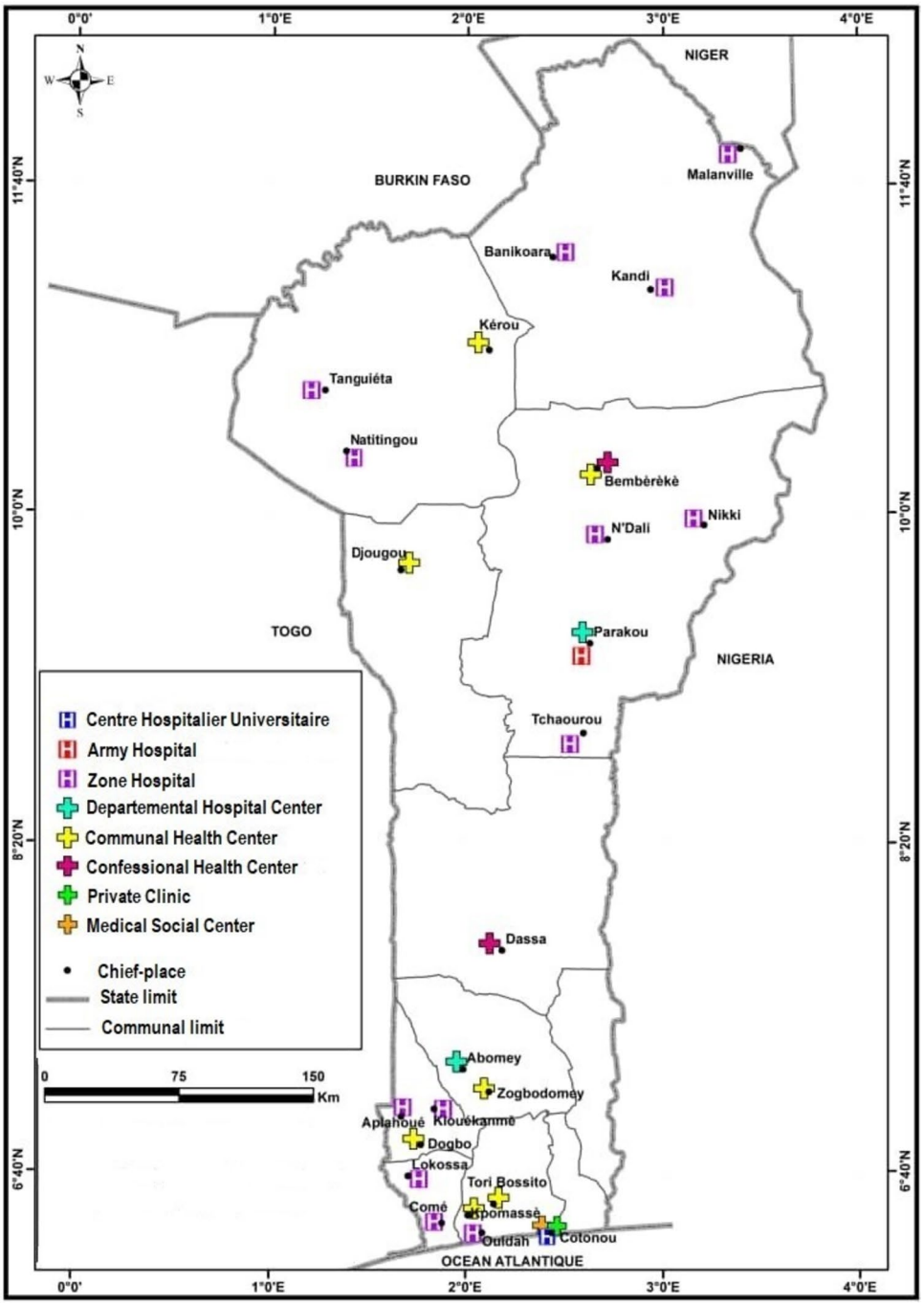

Fig. 2 Hospitals and health centers study area

the slaughterhouses. Adult pigs were 4.1% more likely to be infected with *T. solium* cysticercosis than younger pigs (5.6%).

Of the 4150 pigs examined in the farms, 1892 were kept in total confinement versus 2258 in the free-range. 24 pigs kept in total confinement and 50 in free-range were positive for cysticercosis with a prevalence of 1.3 and 2.2% respectively, ($p < 0.05$).

In the slaughterhouses, the results showed a highly significant variation ($p < 0.05$) in the prevalence of tongue palpation according to the farming systems. Thirty-seven (37) pigs tested positive for tongue palpation with a prevalence of 6.5%, versus 0.4% observed from total confinement (Table 1).

Prevalence of porcine cysticercosis at post-mortem inspection

The results of the post-mortem inspection for porcine cysticercosis presented in Table 2 showed that out of the

Table 1 Prevalence of porcine cysticercosis with the tongue palpation (Benin, 2021)

		Farming			Slaughterhouses		
		NPE	NPI	P (%)	NPE	NPI	P (%)
Department	Alibori	440	3	0.68[a]	13	2	15.38[a]
	Atacora	258	4	1.55[b]	90	12	13.33[b]
	Atlantique	312	6	1.92[c]	9	0	0
	Borgou	692	32	4 .62[d]	332	12	3.61[c]
	Collines	393	5	1.27[e]	75	2	2.67[d]
	Couffo	235	0	0	16	0	0
	Donga	284	1	0.35[f]	-	-	-
	Littoral	114	4	3.51 [g]	102	0	0
	Mono	263	4	1.52[b]	51	5	9.80[e]
	Ouémé	345	6	1.74 [h]	35	1	2.86[f]
	Plateau	398	8	2.01[i]	50	2	4 [g]
	Zou	416	1	0.24[j]	19	2	10.53 [h]
	Total	4150	74	1.78	792	38	4.79
Breed	Crossbred	1620	21	1.29[a]	213	0	0[a]
	Local	2530	53	2.09[b]	579	38	6.56[b]
	Total	4150	74	1.78	792	38	4.79
Sex	Female	2436	42	1.72[a]	473	20	4.23[a]
	Male	1714	32	1.87[b]	319	18	5.64[b]
	Total	4150	74	1.78	792	38	4.79
Age (A)	$0 \leq A < 3$	757	4	0.53[a]	-	-	-
	$3 \leq A < 12$	2880	51	1.77[b]	359	20	5.57[a]
	$A \geq 12$	513	19	3.70[c]	433	18	4.16[b]
	Total	4150	74	1.78	792	38	4.79
Farming systems	Total confinement	1892	24	1.27[a]	229	1	0.44[a]
	Free-range	2258	50	2.21[b]	563	37	6.57[a]
	Total	4150	74	1.78	792	38	4.79

NPE = Number of Pigs Examined; NPI = Number of Pigs Infected; P = Prevalence; (A): Age in month; For each variation factor, the letters (a, b, c, …, i) in superscript of the prevalence rate values, indicate a significant difference between the latter when they are themselves different

792 pigs inspected, 62 were positive (7.8%). The cases of massive infestation (a total of 09 cases) were diagnosed. These cases, representing a prevalence of 1.13%, were wholly condemned. The lesion locations were varied. Cysticerci were found in high numbers in the fillets, tongue and heart, thigh, shoulder and masseter muscles. Figure 3 shows pictures of them strewed with cysticerci taken during post-mortem inspection.

According to the departments of the country, the results of the post-mortem inspection indicated higher prevalences of *Taenia solium* cysticercosis in the departements of Alibori, Atlantique and Atacora than elsewhere, 23.1, 22.2 and 15.5%, respectively. The others departements showed a relatively low prevalence. Adult pigs were more frequently affected than younger ones (Table 2).

Seroprevalence of porcine cysticercosis

Out of the 460 samples tested, 191 were of ELISA positive (41.5%). The highest prevalence was recorded in the department of Atacora (48.5%) followed by the one of Borgou (45.6%). The lowest prevalence was observed in the department of Donga (13.6%). There was a highly significant variation ($p < 0.05$) by sex, age and breed (Table 3). The majority of adult pigs aged 12 months (69.7%) were tested positive. With regard to the breed, a seroprevalence of 51.9% was observed in local breed pigs versus 19.6% for crossbred.

In the free-range system, a seroprevalence was 47.7% versus 28.9% in the total confinement (Table 4). The seroprevalence was higher in farms with a poor sanitary program (41.5%) than in farms with a rigorous sanitary program (17.3%).

Table 2 Prevalence of cysticercosis at post mortem inspection (Benin, 2021)

Variables	Modalities	Slaughterhouses		
		NPE	NPI	P (%)
Department	Alibori	13	3	23.08[a]
	Atacora	90	14	15.56[b]
	Atlantique	9	2	22.22[c]
	Borgou	332	18	5.42[d]
	Collines	75	8	10.67[e]
	Couffo	16	0	0
	Donga	-	-	-
	Littoral	102	4	3.92[f]
	Mono	51	5	9.80[g]
	Ouémé	35	4	11.43[h]
	Plateau	50	2	4[i]
	Zou	19	2	10.53[e]
Breed	Total	792	62	
	Crossbred	213	3	6.76[a]
	Local	579	59	9.40[b]
Sex	Total	792	62	
	Female	473	32	6.76[a]
	Male	319	32	9.40[b]
	Total	792	62	7.83
Age (A)	$0 \leq A < 3$	206	9	4.37[a]
	$3 \leq A < 12$	359	27	7.52[b]
	$A \geq 12$	227	26	11.45[c]
	Total	792	62	7.83
Farming systems	Total confinement	229	5	2.24[a]
	Free-range	563	57	10.12[b]
	Total	792	62	7.83

NPE = Number of Pigs Examined; NPI = Number of Pigs Infected; P = Prevalence; (A): Age in month; For each variation factor, the letters (a, b, c, …, i) in superscript of the prevalence rate values, indicate a significant difference between the latter when they are themselves different

Assessment of risk factors associated with porcine cysticercosis

Figure 4 presented the risk factors associated with porcine cysticercosis in Benin. Some risk factors were found, namely historical taeniasis cases in the farm, latrine facilities, pig farming systems, latrine use and the departments of origin of the pigs. Historical taeniasis cases (OR = 1.84, CI = 1.06–3.13, P = 0.026) and roaming of pigs (OR = 2.3, CI = 1.3–4.3, P = 0.004) contributed to cysticercosis infection. Adult pigs (OR = 30.13, CI = 12.84–77.11, $p < 0.001$) were more infested than younger pigs (OR = 0.26, CI = 0.08–0.66, P = 0.012). In addition, the departements of Borgou, Collines and Littoral were significantly more infested to cysticercosis.

Frequency of diagnostic tests of human taenia and cysticercosis in the hospitals

Out of the twenty-nine (29) hospitals surveyed, ten (10) hospitals performed diagnostic tests of *Taenia* infestations (34.5%) versus four (04) hospitals for cysticercosis 13.8% (Fig. 5). Diagnostic tests for *Taenia solium* and *Taenia saginata* were performed in 10 and 4 hospitals, 34.4 and 13.8% respectively. Once one (01) hospital carried out the neurocysticercosis diagnosis 3.4 versus 10.3% for the detection of dermal neurocysticercosis.

The frequency of diagnostic tests of human *Taenia* and cysticercosis infestations from 2016 to 2020 according to departments showed a lowest use of parasitic tests for the pathogen complex. In fact, for all the hospitals surveyed, less than 500 *Taenia solium* tests (between 301 and 484 from 2016 to 2020) were performed annually (Table 5). Cysticercosis testing is even uncommon (annual average of 1.2 tests). The proportion of diagnostic test of infestations was not negligible. The overall frequency of diagnostic of the five-year period were 4.6% and 100% for *Taenia solium* and cysticercosis respectively (all six suspected cases were positive). In terms of geographical distribution, among the department

Fig. 3 Muscles strewed with cysticerci identified during post-mortem inspection

Table 3 Variation in porcine cysticercosis seroprevalence according to departments, sex, age and breed (Benin, 2021)

Variables	Modalities	NPE	NPI	SP (%)
Department	Alibori	92	35	38.04[a]
	Atacora	70	34	48.57[b]
	Borgou	136	62	45.59[c]
	Donga	22	3	13.64[d]
	Ouémé	70	28	40[e]
	Plateau	70	29	41.43[f]
	Total	460	191	41.52
Sex	Female	273	82	30.04[a]
	Male	187	109	58.28[b]
	Total	460	191	41.52
Age	0–3	74	10	13.51[a]
	3–12	267	98	36.70[b]
	> 12	119	83	69.75[c]
	Total	460	191	41.52
Breed	Crossbred	148	29	19.6[a]
	Local	312	162	51.9[b]
	Total	460	191	41.52

NPE = Number of Pigs Examined; NPI = Number of Pigs Infected; SP = Sero-prevalence; For each variation factor, the letters (a, b, c, …, i) in superscript of the prevalence rate values, indicate a significant difference between the letter when they are themselves different

Table 4 Variation in seroprevalence of porcine cysticercosis by breeding systems (Benin, 2021)

Variables	Modalities	NPE	NPI	SP (%)
Water Source	SONEB	28	10	35.7[a]
	Borehole	17	4	23.53[b]
	Well	393	169	43.00[c]
	Rivers	22	8	36.36[a]
	Total	460	191	41.52
Feeding	Provender	23	7	30.43[a]
	KR	424	179	42.22[b]
	KR + Provender	13	5	38.46[c]
	Total	460	191	41.52
History of cysticercosis	No	345	148	42.89[a]
	Yes	115	43	37.39[b]
	Total	460	191	41.52
Latrine use	No	282	111	39.36[a]
	Yes	178	80	44.94[b]
	Total	460	191	41.52
Monitoring Health	No	381	158	41.47[a]
	Yes	79	33	41.77[a]
	Total	460	191	41.52
Farming systems	Total confinement	152	44	28.95[a]
	Free-range	308	147	47.73[b]
	Total	460	191	41.52

NPE = Number of Pigs examined; NEP = Number of Pigs Infected; SP = Sero-prevalence; KR: kitchen residue; SONEB = Benin's national water company. For each variation factor, the letters (a, b, c, …, i) in superscript of the prevalence rate values, indicate a significant difference between them when they are themselves different

where the number of examinations performed was greater than 100, the department of Borgou showed the highest proportion of diagnostic test of *Taenia solium* (79 carriers out of 655 examinations, 12.1%) followed by the department of Atlantique (7 carriers out of 401 examinations, 1.7%). The department of Littoral had the lowest proportion (5 cases out of 1005 examinations, 0.5%).

Discussion

Prevalence of cysticercosis

This study determined the prevalence of cysticercosis in livestock and slaughterhouses in Benin using three (3) techniques such as tongue palpation, post-mortem inspection and serodiagnosis. These three techniques have been widely used by several authors (Pouedet 2001; Phiri 2003; Goussanou et al. 2010; Rasamoelina Andriamanivo 2013; Ranivoarisoa 2016; Mopoundza et al. 2019). These techniques have shown that porcine cysticercosis is highly endemic in several departements of Benin.

Using tongue sampling, overall prevalences of 1.8 and 4.8% were observed in farms and slaughterhouses, respectively. However, these proportions are low compared to those reported by a number of authors who investigated cases from countries most severely affected by this zoonosis. This is the case in Madagascar where Ranivoarisoa (2016) reported a prevalence of 8.70% obtained with the same technique in the district of Tsiroanomandidy. This is also the case in Kenya, where tongue palpation revealed a prevalence of 10–14% (Phiri et al. 2003). However, the case of Benin seems more worrying than that of Cameroon where a prevalence of 1.04% is reported by Mopoundza et al (2019). It is also important to take these measured contamination levels as minimalist. This is because the low sensitivity of the tonguing technique is well known (Eshitera et al. 2012). This technique can only detect high parasite loads during a massive infestation (Gonzalez et al. 1990; Dorny et al. 2009). However, it is still widely used according to Gonzalez et al (1990) because of its convenience (inexpensive and practicable without great technical skill). The second technique (Carcass inspection) used in this study, is more specific, although it's also considered to have low sensitivity. It does not reflect the true prevalence of cysticercosis according to Sakai et al (1998) and Dorny et al. (2000). In this study, the prevalence of porcine cysticercosis obtained at post mortem inspection was 7.82%, significantly higher than the prevalence revealed by tongue

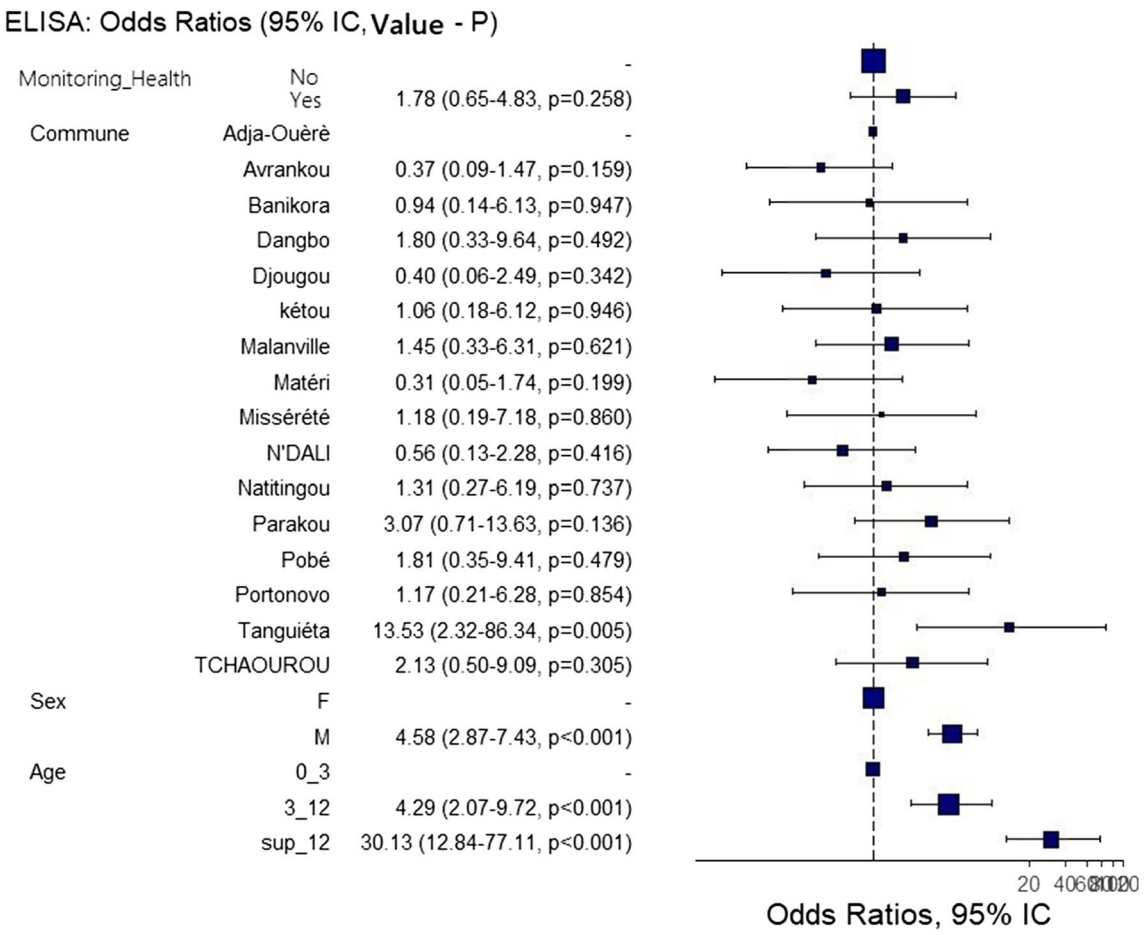

Fig. 4 Risk factors for cysticercosis seroprevalence

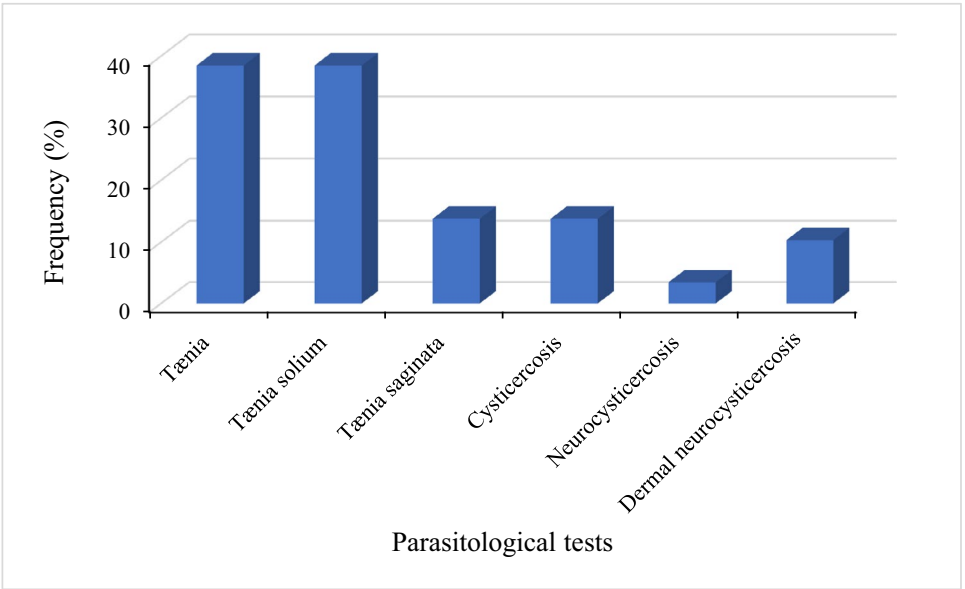

Fig. 5 Frequency of parasitological examination for of human *taenia* and cysticercosis in the hospitals and health centers

Table 5 Frequency of diagnostic tests of human *taenia* and *cysticercosis* in the Beninese hospitals and health centers (Benin, 2021)

	Taenia solium			Cysticercosis			Neurocysticercosis			Dermal neurocysticercosis		
	NTP	NCP	P (%)	NTP	NCP	P (%)	NTP	NCP	P (%)	NTP	NCP	P (%)
Years												
2016	301	1	0.33	0	0	0	0	0	0	0	0	0
2017	428	29	6.78	1	1	100	0	0	0	1	1	100
2018	438	12	2.74	1	1	100	0	0	0	1	1	100
2019	484	26	5.37	2	2	100	0	0	0	2	2	100
2020	476	29	6.09	2	2	100	1	1	100	1	1	100
Departments												
Atacora	0	0	0	0	0	0	0	0	0	0	0	0
Alibori	13	0	0	0	0	0	0	0	0	0	0	0
Atlantique	401	7	1.75	1	1	100	1	1	100	0	0	0
Borgou	655	79	12.06	1	1	100	0	0	0	4	4	100
Couffo	4	2	50	4	4	100	0	0	0	4	4	100
Collines	49	4	8.16	0	0	0	0	0	0	0	0	0
Donga	0	0	0	0	0	0	0	0	0	0	0	0
Littoral	1005	5	0.5	0	0	0	0	0	0	0	0	0
Mono	0	0	0	0	0	0	0	0	0	0	0	0
Zou	0	0	0	0	0	0	0	0	0	0	0	0

NTP: Number of tests performed; NPC: Number of Positive Cases; P = Proportion (%)

palpation (4.8%). This could be explained by the fact that post-mortem inspection detects both light and heavy infestations. This proportion of 7.82% indicates the importance of the zoonotic risk in Benin. It should be noted that this risk is much higher than those estimated by Goussanou (2010) in southern Benin (0.2%) and by Gonzalez et al. (2004) and Mopoundza et al (2019) in Cameroon (1.7% and 2.2% respectively). This is slightly higher than the prevalence of 5.6% and 4.6% reported by Eshitera et al (2012) in Kenya and Porphyre et al (2015) in Madagascar, respectively. Serodiagnosis revealed a seroprevalence of 41.5%. This suggests that the *Taenia solium* / *Cysticercus cellulosae* complex manages to complete its cycle and circulates between Beninese consumer populations and farmed pigs. In any case, the level of risk of contamination is very high throughout the country, and is more acute in some departments of the country, such as Alibori, Atlantique and Atacora. Those three departments are similar in three ways that may explain their infestation. First, they are areas of high pig production with a widespread tendency for animals to roam; a practice recognised as a powerful risk factor for pig contamination. Second, there is rural poverty characterized by the scarcity of latrines; a second factor favouring the contamination of pigs through the ingestion of soiled faeces emitted on rubbish dumps or in the vegetation in built-up areas. Finally, there is the low price of pigs, which increases the frequency and relative quantities ingested.

Risk factors for porcine cysticercosis in Benin

Porcine cysticercosis is known to be associated with certain risk factors such as pigs roaming, fecal peril (Pouedet et al. 2002; Rahantamalala et al. 2016). In the present study, departement of origin, age classes of pigs, rearing pattern, farm history of cysticercosis, sex and watering pattern were found to be the risk factors associated with porcine cysticercosis in Benin. Pig husbandry practices vary from one department to another in terms of breeding, feeding and health monitoring. In several departments of Benin, pigs are raised in rural areas where animals left to roam are often in direct contact with human feces thus favouring pig infestation (Sreedevi et al. 2012; Thys et al. 2015; Tassou et al. 2021a). The study shows that the risk to cysticercosis increases with age class. Adult pigs are at the highest risk for infestation than younger pigs. These results are consistent with those reported by (Pondja et al. 2010; Ngwing et al. 2012) in Mozambique and Cameroon respectively. The roaming animals are in the present study more infested to cysticercosis than animals kept in confinement. This same observation was made by Rasamoelina-Andriamanivo et al (2013), who demonstrated that pig roaming coupled with human fecal peril is known to be the most important risk factors for the persistence of human taeniasis and porcine and human cysticercosis. Prevalence was significantly higher in boars compared to sows. Boars are generally found to be more ambulatory and active in foraging than sows and are therefore more infested to the consumption of human faeces

containing *Taenia solium* eggs as reported by Sikasunge et al (2008) in Zambia, where male sex was identified as a risk factor. As for the type of water used for watering pigs, the risk could be explained by the presence of cysticerci eggs in drinking water contaminated by humans.

Diagnostic methods and choice of serological kit

In the epidemiology of *Taenia solium* cysticercosis, it is mainly pigs carrying live cysts that present a public health risk. Diagnosis of cysticercosis in pigs can be made before slaughter (ante-mortem) or after slaughter (post-mortem) using various techniques such as tongue examination, post-mortem inspection of carcasses and serological techniques (Pouedet 2001; Eshitera et al. 2012). In the present study, a significant difference ($P < 0.05$) was obtained between the tongue palpation, post-mortem inspection and serodiagnosis with proportions of 2.3; 7.9 and 41.5% respectively. According to Dorny et al. (2009), the first two diagnostic methods do not allow a true estimation of porcine cysticercosis. The tongue palpation in the absence of massive infestation has a low sensitivity (Gonzalez et al. 1990; Dorny et al. 2009; Eshitera et al. 2012), especially with the possibility of false positives due to mechanical lesions or caused by actinobacteria (Pouedet et al. 2002). The tongue palpation and post-mortem inspection are two complementary techniques for estimating the prevalence of cysticercosis. They are commonly used diagnostic methods for the detection of cysticercosis due to their low cost but with rapid and palpable results. Tongue palpation is not a definitive diagnosis, and the prevalences determined by this technique would in fact only be a minimum value of the prevalence of infestation as tongue palpation underestimates the true prevalence of cysticercosis (Sarti et al. 1992). Furthermore, this method only detects cysticerci in the tongue in the case of massive infestation, which is why post-mortem inspection has been supplemented with the tongue palpation technique in order to complete the results obtained by tongue palpation. Under these conditions, the diagnostic method that can identify animals with live cysts is the Ag-ELISA serological technique (Dorny et al. 2003; Murell et al. 2005; Lightowlers et al. 2016). Serological methods based on antibody detection, despite their moderate specificity and sensitivity (Sciutto et al. 1998; Dorny et al. 2003), have the disadvantage of overestimating the number of pigs carrying cysts, as an animal that has been in contact with the parasite and no longer carries it could retain the antibodies and be detected as positive (Garcia et al. 2001; Murell et al. 2005). In addition, due to maternal antibodies, the interpretation of a positive test in a young person younger than three (3) months of age may be incorrect (Pawlowski et al. 2005). For these reasons, the antigen detection technique (Ag-ELISA B158/B60) was chosen as it is more specific and sensitive than the Ag-ELISA HP10 (Sciutto et al. 1998; D'Souza and Hafeez 1999; Dorny et al. 2004). However, this technique cross-reacts with *Taenia hydatigena* antigens (Dorny et al. 2003) but the prevalence of *Taenia hydatigena* in pigs in sub-Saharan Africa is estimated to be low (Dorny et al. 2004). Also, bacterial contamination or repeated freeze–thaw cycles of the samples may affect the absorbance values. When interpreting the results, several samples showed an OD $0.8 \leq$ Ag index ≤ 1.3, which is considered a doubtful result. The manufacturer's instructions state that for doubtful results, the test should be repeated, but given the high price and the absence of the kit locally, these tests could not be repeated and the samples considered negative. The reasons may be: (i) an error in diluting the wash buffer due to the inaccuracy of the graduated cylinder or the failure of the micropipettes; (ii) a handling error: insufficient number of washes; (iii) poor storage; (iv) degradation of reagents due to frequent power cuts; (v) a fault during plate reading: parameters or state of the ELISA reader.

Relationship between human taenia cases and cysticercosis

This study was conducted in order to highlight the rarity of prescriptions for parasitic tests for *Taenia*/cysticercosis in Beninese hospitals. Of course, the analysis is not free of bias. It was based only on a review of medical records and documents where these existed. Only the large health centers regularly kept and maintained their records. However, parasitological examinations for human *taenia* and cysticercosis are not of the regular laboratory practice. Out of the twenty-nine (29) hospitals surveyed from 2016 to 2020, only ten (10) performed such examinations. It should be noted that in fact for the reported cases of cysticercosis they were reported and then confirmed following a proven clinical diagnosis. There was never a request for further examination following a suspicion. This confirms the remarks of WHO (2021) deploring that human cysticercosis remains a neglected disease in the Sub-Sahara Africa regions. Nevertheless, Benin is an endemic region (positive diagnoses in almost all departments), probably because all the elements that favour the *Taenia solium* cycle are present: widespread open defecation, pigs in free roaming, access to human feces by free-ranging animals, human-pig promiscuity, lack of food and general hygiene, clandestine slaughter, and lack of veterinary control of meat (Clément 2016). Also, in Benin, the results of the activity report of the zoonoses prioritisation workshop organised by component 1 of the Regional Project for Strengthening Disease Surveillance Systems (REDISSE) define 06 priority zoonoses (Zoonotic Influenza (including Avian Influenza), Rabies, Haemorrhagic Fevers (RVF, Ebola, Lassa, Crimea Congo), Anthrax, Severe Acute Respiratory Syndrome (SARS) and Trypanosomiasis),

which does not include cysticercosis. However, pig farming in Benin is mainly extensive or a traditional system, with the main characteristic being the breeding of local breeds (61%) and the wandering of pigs (54.4%). This roaming, combined with the proximity of humans and the practice of free-range defecation by people in rural and peri-urban areas, is responsible for the spread of several zoonoses, including cysticercosis. Already described with a seroprevalence of 72.2% by (Goussanou et al. 2013) in the communes of south-eastern Benin, cysticercosis remains an important public health problem although it is not taken into account by component 1 of REDISSE. In the present study, at post-mortem inspection, a prevalence of 7.8% and a seroprevalence of 41.5% were obtained. Humans are the only known definitive host of the tapeworm (*Taenia solium*) that causes human taeniasis and pigs are the intermediate host through ingestion of eggs from human excreta. These prevalences, combined with epidemiological factors such as the roaming of animals, human-pig promiscuity, particularly in rural and peri-urban areas, the clandestine slaughter of pigs and the inadequacy of veterinary control, faecal peril and the poverty of the population, suggest that the *Taenia/cysticercosis* complex remains a major public health problem which is still neglected in Benin. The epidemiological assessment of cysticercosis and taeniasis infestations over a five-year period showed that, out of twenty-nine (29) hospitals surveyed, 34.5% tested individuals for taeniasis and 13.8% for cysticercosis. These results highlight the neglected nature of this zoonosis and the need to classify it among those listed as a priority. In addition, national efforts must be made to control and monitor its spread and even its elimination. Thus, strengthening the control of this disease would make a major contribution to improving pig production, poverty and climate change.

Conclusion

This study established the prevalence, risk factors of swine cysticercosis and statistics of human cases in the departement of Benin. It revealed the endemicity of swine cysticercosis in most departments. The national seroprevalence of 41.5% suggests that slaughterhouse findings greatly underestimate the level of actual human contamination by pigs. This situation is all the more predictable since previous studies have shown that the appetite of Beninese people for pigs and especially the type of preparation preferred (skewer) lead to a high risk of transmission of parasitic cysts to consumers, who thus become carriers of *Taenia solium* and thus potential sources of contamination of pigs. The danger is particularly high in the departements of Atacora, Borgou, Alibori, and Littoral, where nearly half of the pig population lives with evidence of the infection in their blood. The frequency of hospitals having performed parasitological examinations for tapeworms is 34.5% and 13.8% for the diagnosis of cysticercosis. Despite this low proportion of examinations, several positive cases were observed. During the five-year period covered by this study, more than half of the institutions and hospitals did not perform any parasitological consultations for the diagnosis of cysticercosis and tapeworms. This indicates the difficulty in obtaining epidemiological data on the *teniasis/cysticercosis* complex in sub-Saharan African countries and confirms the neglected tropical disease status of cysticercosis in these countries.

Conflict of interests

The authors declare no conflict of interest.

Author contributions Wassiou Abdou Tassou and Josias Steve Adjassin worked on the conceptualization, sampling, investigation, and methodology and prepared tables and figure. Sabbas Attindéhou, Oubri Bassa Gbati and Sahidou Salifou worked on supervision and has reviewed the manuscript. The first draft of the manuscript was written by Wassiou Abdou Tassou and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Declarations

Competing interests The authors declare no competing interests.

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