INTRODUCTION

*Taenia solium* taeniasis/cysticercosis, a parasitic zoonotic disease transmitted between pigs and humans, is endemic in most of sub-Saharan Africa where its persistence is associated with poor sanitary conditions including open-air defecation, free-range pig husbandry, lack of awareness or control of diseases using available tools (Assana et al., 2013). The life cycle of *T. solium* involves humans as the natural definitive hosts for the adult tapeworm, which lodges in the intestines of individuals. In the conditions where latrines are unavailable or not used, eggs of the tapeworm are released with the human feces in the environment. Following ingestion by pigs, eggs hatch and oncospheres develop in pig tissues causing porcine cysticercosis. The life cycle of the parasite is completed when uncooked contaminated pork is consumed by humans, leading to intestinal adult tapeworm infection (taeniasis). Humans may also be infected by cysticerci following accidental ingestion of *T. solium* eggs. In humans, cysticerci may establish in the brain, causing neurocysticercosis (NCC). NCC-associated epilepsy was recently considered as the parasitic food-borne infection having the largest number of disability adjusted life years (DALY) in the world (Torgerson et al., 2015). There has been a growing urge to eliminate *T. solium* porcine cysticercosis using vaccination and treatment of pigs to reduce or eliminate indirectly the burden of human taeniasis and neurocysticercosis in endemic areas including Africa. However, there is a dearth of information on the epidemiology of the disease and pig production systems in Africa. Comprehensive reliable epidemiological data on the size and distribution of pigs at risk of cysticercosis and infected pigs are essential to understand the disease importance in pig populations for an effective control…

Pig populations at risk of *Taenia solium* cysticercosis and subsequent financial losses in West and Central Africa

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Summary

*Taenia solium* cysticercosis is a serious problem for pig breeders and a major public health risk in Africa. There is growing interest in eradicating porcine cysticercosis in endemic areas to reduce or eliminate indirectly human taeniasis and neurocysticercosis. However, there is a lack of reliable data on pig populations affected by the disease because of the unavailability of specific diagnostic tools. A stochastic model helped to estimate pig populations at risk of *T. solium* cysticercosis, prevalence of the disease, and related financial losses in West and Central Africa. Results revealed that over 16 million pigs (95% confidence interval [CI]: 13.7–20.1) were kept in conditions favorable to *T. solium* cysticercosis. The estimated number of pigs infected with this disease was 6.89 million (95% CI: 4.26–9.88), i.e. 30.0% prevalence (95% CI: 26.6–43.8). The estimated direct financial losses for pig farmers and traders were 165 million euros (95% CI: 117.2–213.0). The study highlights the needs to raise awareness on the situation and implement control measures against *T. solium* taeniasis/cysticercosis in both regions.

Pig cysticercosis in West and Central Africa

We emphasized the agricultural burden caused by this zoonosis in *T. solium* risk of infection, the expected prevalence of the disease, and factors favoring porcine *T. solium* cysticercosis. During the cropping and rainy seasons, pigs were kept in enclosures but had access to home scraps and waste including human feces when latrines were not used. In the intensive system where the animals were provided feed and housing. In the scavenging system, animals had access to home scraps and waste. During the cropping and rainy seasons, pigs were kept in enclosures but were released after the crop harvest and dry seasons to roam freely.

**Study area**

In this study, 28 countries are considered to belong to West and Central Africa regions (Zoli et al., 2003). South Sudan has been included in the Central Africa region since its independence in 2011. All major species of domestic livestock are reared in these regions.

Central Africa comprises 13 countries (Angola, Burundi, Cameroon, Central African Republic, Chad, Congo, Democratic Republic of Congo, Equatorial Guinea, Gabon, Rwanda, Sao Tome and Principe, South Sudan and Zambia). According to country statistics (www.geonames.org), the region has a population of 167,082,216 inhabitants in a total area of 7,734,364 square kilometers. Extending from the equatorial forest of Congo Basin to the Saharan desert zone of the north of Chad, it holds various characteristics and climates. The population is largely engaged in rural activities that include crop and animal productions.

West Africa comprises 15 countries (Benin, Burkina Faso, Cabo Verde, Cote d’Ivoire, Gambia, Ghana, Guinea, Guinea Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, Togo). The total human population is 296,203,410 in an area of 5,012,903 km² with the highest population in Nigeria (www.geonames.org). The area holds much sociocultural, economic, demographic and religious diversity. Similarly to Central Africa, the human population is mainly engaged in agricultural activity.

Cultural and linguistic evidences and local pig breeds strongly suggest that pig keeping was common in many areas of West and Central Africa before the introduction of exotic breeds from Europe in the fifteenth century (Blench, 2000). Pig production has increased during the past decade from 5% to 10% (Porphyre, 2009; FAO, 2017). However, the African swine fever remains a major limiting factor for the development of modern pig production in both regions.

**Materials and methods**

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**Pig populations at risk of infection with *T. solium* cysticercosis**

The parameters used to estimate pig populations at risk of *T. solium* cysticercosis infection in West and Central Africa are presented in Tables I and II and Figure 1. These parameters were gathered from a comprehensive literature review of published community studies on pig management, environmental conditions favoring *T. solium* transmission, and epidemiological data on porcine cysticercosis in West and Central Africa. Experts also provided additional unpublished data. Data on pig populations in each country were compiled from the Food and Agriculture Organisation database (FAO, 2017).

**Pig management systems**

Pig management systems in West and Central Africa are presented in Table II. Pigs were mainly kept by small-scale farmers under traditional systems, which represented 60–90% of total pig populations in the regions. Briefly, there were the scavenging system where the pig searched for its own feed, the semi-intensive system where the majority of the feed consisted of domestic waste and the animals were enclosed only during the night, and the intensive system where the animals were provided feed and housing. In the scavenging system, animals had access to home scraps and waste including human feces when latrines were not used. During the cropping and rainy seasons, pigs were kept in enclosures but were released after the crop harvest and dry seasons to roam freely.

**Factors favoring porcine *T. solium* cysticercosis**

An exposure factor for cysticercosis infection is defined in this study as the environment where the life cycle of *T. solium* is completed. Several conditions favoring *T. solium* transmission have been reported in endemic areas of Africa (Tables I and II). These conditions among
others include poor quality of life in rural areas, inadequate access to latrines, financial and knowledge constraints leading to major limitations to improved pig management and latrine building, open defecation enhanced by a lack of knowledge regarding transmission of the parasite, financial barriers to implement control measures, and lack of public sensitization (Ngowi et al., 2017). Except for Muslim localities, all areas in West and Central Africa where pigs are traditionally reared had environmental conditions that favor transmission of *T. solium* cysticercosis.

**Epidemiological data on porcine cysticercosis**

Epidemiological data showed irregular reporting of porcine cysticercosis in West and central Africa; the diagnostic methods used were

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Distribution</th>
<th>Value/range</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Live pig production</td>
<td>Fixed</td>
<td>22,562,685</td>
<td>FAO, 2017</td>
</tr>
<tr>
<td>Live pig population in each country</td>
<td>Fixed</td>
<td>6,800–7,066,905</td>
<td>FAO, 2017</td>
</tr>
<tr>
<td>Pork in each country (tons)</td>
<td>Fixed</td>
<td>115–239,400</td>
<td>Survey in Cameroon (Assana, unpubl. data)</td>
</tr>
<tr>
<td>Herd size (small-scale farmers)</td>
<td>Gamma</td>
<td>4–10</td>
<td>Survey in Senegal (A. Teko-Agbo, pers. commun.)</td>
</tr>
<tr>
<td>Population at risk of infection (%)</td>
<td>Uniform</td>
<td>60–90</td>
<td>Porphyre, 2009</td>
</tr>
<tr>
<td>Prevalence of porcine cysticercosis in each country determined by tongue or meat exam</td>
<td>Uniform</td>
<td>0.2–39</td>
<td>Res. literature (Table III)</td>
</tr>
<tr>
<td>Heavily infected pigs destroyed at slaughterhouses</td>
<td>Beta</td>
<td>13,114</td>
<td>Survey in Cameroon (G. Nsingo, pers. commun.)</td>
</tr>
<tr>
<td>Intervention cost (pig treatment/farmer) (€)</td>
<td>Uniform</td>
<td>0.4–1.5</td>
<td>Survey in Cameroon (G. Nsingo, pers. commun.)</td>
</tr>
<tr>
<td>Losses caused by porcine cysticercosis</td>
<td>Fixed</td>
<td>30% of price of adult pig</td>
<td>Praet et al., 2009</td>
</tr>
<tr>
<td>Pig price at the market (€)</td>
<td>Uniform</td>
<td>70–122</td>
<td>Survey in Cameroon (G. Nsingo, pers. commun.)</td>
</tr>
<tr>
<td>Pig price at the trader’s level (€)</td>
<td>Uniform</td>
<td>90–180</td>
<td>Survey in Cameroon (G. Nsingo, pers. commun.)</td>
</tr>
<tr>
<td>Num. of pigs a farmer can sell / year</td>
<td>Uniform</td>
<td>2–6</td>
<td>Survey in Cameroon (Assana, unpubl. data)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Systems</th>
<th>Housing</th>
<th>Ownership</th>
<th>Feeding</th>
<th>% (systems)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scavenging</td>
<td>None</td>
<td>Often communal</td>
<td>None</td>
<td>5–9</td>
<td>Antunes et al., 2015</td>
</tr>
<tr>
<td>Herded</td>
<td>None</td>
<td>Individual</td>
<td>Seasonal diet</td>
<td>20–40</td>
<td>Assana et al., 2001; Antunes et al., 2015</td>
</tr>
<tr>
<td>Tethered</td>
<td>None</td>
<td>Individual</td>
<td>Household waste</td>
<td>1–5</td>
<td>Blench, 2000</td>
</tr>
<tr>
<td>Semi-intensive</td>
<td>Semi-permanent construction from local materials</td>
<td>Individual smallholders</td>
<td>Household waste, millet brew waste, millet and maize bran and sometimes grown grass</td>
<td>60–90</td>
<td>Blench, 2000; Gweba et al., 2010; Ngowi et al., 2017</td>
</tr>
<tr>
<td>Intensive</td>
<td>Modern pen made of concrete with zinc roofing Semi-permanent construction from local materials</td>
<td>Urban-based entrepreneurs and businessmen Small size intensive pig farm in rural areas</td>
<td>Agro-industrial by-products</td>
<td>10</td>
<td>Ngwing et al., 2012</td>
</tr>
</tbody>
</table>
tongue examination, meat inspection and serology (Table III). However, the extensive seroepidemiological data available on porcine cysticercosis were not used in this study. Cross-reaction between *T. hydatigena* and *T. solium* in serological tests could overestimate the real prevalence of porcine *T. solium* cysticercosis in endemic areas where *T. hydatigena* was present. Although data on *T. hydatigena* in pigs have been reported in a few countries including Nigeria (Fabiyi, 1979), Ghana (Permin et al., 1999), Burkina Faso (Dermauw et al., 2016) and Zambia (Chembensofu et al., 2017), this parasite could be common in pigs in West and Central Africa along with *T. solium*. Moreover, transient antibody responses and short-term antigen presence have been reported in *T. solium* cysticercosis serology in humans (Mwape et al., 2013), which might be the case for porcine cysticercosis.

Annual financial losses caused by porcine cysticercosis

The pork trade chain involves farmers, traders, butchers, retailers and consumers (Figure 1). In many areas of endemic countries, traders examine the pig’s tongue and the pig’s price depends on the presence or absence of cysts. Once purchased, the trader transports the pig to a butcher or a retailer. The latter will make sure that the pig’s tongue is free of cysts. At the abattoir, the entire infected animal can be lost. It is assumed that pork with a high cyst burden is more detectable than pork with a low cyst burden. In the present study, economic losses for pig keepers were estimated based on 30% reduction of the price of a cysticercosis-infected pig in Cameroon (Praet et al., 2009; Ngwing et al., 2012). The purchase price of a healthy pig has been reported in Benin (Goussanou et al., 2013) and Cameroon (Ministry of Livestock, Fisheries and Animal Industries) and ranges from 70 to 122 euros (45,000 to 80,000 CFA francs from Central Africa [XAF]) and 90 to 180 € (60,000 to 118,000 XAF) at the level of pig farmers and traders, respectively. For the economic losses at the level of butchers, the number of carcasses destroyed or seized in the abattoir of Yaounde in Cameroon (G. Nsingo, 2013, pers. commun.), Senegal (A. Teko-Agbo, 2012, pers. commun.) and Benin (Goussanou et al., 2013) was assumed to be similar to those in the other countries of West and Central Africa. The cost of interventions such as treatment of animals was estimated based on information obtained from Cameroon, Tanzania and Uganda (E. Assana and S. Gumbi, unpubl. data). In Cameroon, pig farmers usually try to treat their pigs if they find them infected during routine tongue palpation before bringing them to the market. For this purpose, they do self-prescription and use indigenous products (E. Assana, unpubl. data).

### Table III

*Taenia* sp. prevalence in pigs from tongue or meat inspection in West and Central Africa

<table>
<thead>
<tr>
<th>Countries</th>
<th>Prevalence (%)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angola</td>
<td>6.8</td>
<td>Kama, 1998</td>
</tr>
<tr>
<td>Benin</td>
<td>3.7–8.4</td>
<td>Goussanou et al., 2013</td>
</tr>
<tr>
<td>Burkina Faso</td>
<td>0.6–30*</td>
<td>Geerts et al.; 2004, Dermauw et al., 2016</td>
</tr>
<tr>
<td>Burundi</td>
<td>2–39</td>
<td>Newell et al., 1997</td>
</tr>
<tr>
<td>Cameroon</td>
<td>11–22</td>
<td>Assana et al., 2001; Ngwing et al., 2012</td>
</tr>
<tr>
<td>Chad</td>
<td>16.2–26</td>
<td>Assana et al., 2001</td>
</tr>
<tr>
<td>Cote d'Ivoire</td>
<td>2.5</td>
<td>Geerts et al., 2004</td>
</tr>
<tr>
<td>DRC</td>
<td>5.5–10</td>
<td>Praet et al., 2010</td>
</tr>
<tr>
<td>Gambia</td>
<td>0.2</td>
<td>Secka et al., 2010</td>
</tr>
<tr>
<td>Ghana</td>
<td>11.7</td>
<td>Permin et al., 1999</td>
</tr>
<tr>
<td>Nigeria</td>
<td>5.8–20.5</td>
<td>Onah and Chiejina, 1995; Gweha et al., 2010</td>
</tr>
<tr>
<td>Rwanda</td>
<td>20</td>
<td>Geerts et al., 2004</td>
</tr>
<tr>
<td>Senegal</td>
<td>1.2</td>
<td>Secka et al., 2010</td>
</tr>
<tr>
<td>Togo</td>
<td>17</td>
<td>Dumas et al., 1990</td>
</tr>
<tr>
<td>Zambia</td>
<td>10.8</td>
<td>Sikasunge et al., 2008</td>
</tr>
</tbody>
</table>

* DRC: Democratic Republic of Congo
* This prevalence at abattoir level is underestimated. In Burkina Faso pigs perceived to be infected based on tongue palpation are rarely sent to official abattoirs (Dermauw et al., 2016). The seroprevalence of porcine cysticercosis (antigen detection) is approximated 40% (Ganaba et al., 2011; Dermauw et al., 2016) within which PCR results showed that only one quarter could be *T. hydatigena* antigen. Thus 30% of pigs infected with *T. solium* were detected at farm level by tongue palpation and excluded from the abattoir.
Cysticercose porcine en Afrique de l’Ouest et centrale

**R model**

We used the R model described by Praet et al. (2009) and Trevisan et al. (2017). Briefly, R software (Development Core Team, version 3.4.0) uses the Markov Chain Monte Carlo (MCMC) technique and allows calculating 95% confidence intervals. The parameters compiled in Table I were used to build the R function. A flowchart was constructed to estimate the proportion of pig populations at risk of infection with *T. solium* and of infected animals (Figure 1).

To estimate the prevalence of porcine cysticercosis, the sensitivity of meat inspection and tongue examination as visual tests was considered to be between 20–50% and specificity was assumed to be 100% (Dorny et al., 2004). Consequently, many infected carcasses were missed and only the heavily infected ones were detected by these tests. Moreover, observations in abattoirs in Cameroon showed that about 10% of infected pigs were condemned during veterinary inspections (G. Nsingo, unpubl. data), the rest was marketed at normal prices. Similar findings have been reported in Benin (Goussanou et al., 2013). The expected true number of infected pigs and true prevalence of porcine cysticercosis were computed with the R model based on the characteristics of tongue and meat inspection as diagnostic tools (Table IV). The R function was simulated from 10,000 to 200,000 iterations to compute the optimal number of pigs at risk of *T. solium* infection, the number of infected pigs, the expected prevalence of porcine cysticercosis, and the related cost. Different probabilistic distributions were used according to the information available on each of the parameters in Table I. The R model is presented in Supplementary Materials I, II and III.

**RESULTS**

**Pig population size at risk of *T. solium* infection**

Pigs are present in all countries of West and Central Africa (Table V). Angola, Burkina Faso, Cameroon and Nigeria had the highest pig population at risk of *T. solium* cysticercosis infection. The total

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**Table IV**

Two-by-two contingency table containing parameters used in the stochastic model to estimate the prevalence of *Taenia solium* in pigs in West and Central Africa

<table>
<thead>
<tr>
<th>Outcome of tongue/meat inspection</th>
<th>Proportion of pigs found infected with cysticerci</th>
<th>Proportion of pigs found free of cysticerci</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion of infected pigs</td>
<td>$P \times Se$</td>
<td>$(1-P) \times (1 - Sp)$</td>
<td>$P$</td>
</tr>
<tr>
<td>Proportion of infection-free pigs</td>
<td>$(1 - P) \times (1 - Sp)$</td>
<td>$P\times (1 - Se)$</td>
<td>$1 - P$</td>
</tr>
<tr>
<td>Total</td>
<td>$P \times Se + (1 - P) \times (1 - Sp)$</td>
<td>$P \times (1 - Se) + (1 - P) \times Sp$</td>
<td>$1$</td>
</tr>
</tbody>
</table>

$P \times Se + (1 - P) \times (1 - Sp) = P'; P = (P' + Sp - 1) / (Se + Sp - 1)$

where $P'$ represents the proportion of pigs found infected with *Taenia solium* during tongue/meat inspection, $P$ the true prevalence of *T. solium* cysticercosis in pigs (estimated by the stochastic model presented in Suppl. Mat.), $Se$ the sensitivity of tongue/carcass inspection comprised between 0.20 and 0.50 (Dorny et al., 2004), and $Sp$ the specificity of tongue/carcass inspection and is equal to 1.

**Table V**

Live pig populations at risk of *Taenia solium* cysticercosis in West and Central Africa

<table>
<thead>
<tr>
<th>West Africa</th>
<th>Central Africa</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Countries</strong></td>
<td><strong>Pig populations</strong></td>
</tr>
<tr>
<td>Benin</td>
<td>431,000</td>
</tr>
<tr>
<td>Burkina Faso</td>
<td>2,345,800</td>
</tr>
<tr>
<td>Cabo verde</td>
<td>85,000</td>
</tr>
<tr>
<td>Cote d’Ivoire</td>
<td>370,000</td>
</tr>
<tr>
<td>Gambia</td>
<td>8,192</td>
</tr>
<tr>
<td>Ghana</td>
<td>682,000</td>
</tr>
<tr>
<td>Guinea</td>
<td>106,000</td>
</tr>
<tr>
<td>Guinea Bissau</td>
<td>463,000</td>
</tr>
<tr>
<td>Liberia</td>
<td>290,000</td>
</tr>
<tr>
<td>Mali</td>
<td>77,288</td>
</tr>
<tr>
<td>Niger</td>
<td>42,500</td>
</tr>
<tr>
<td>Nigeria</td>
<td>7,066,905</td>
</tr>
<tr>
<td>Senegal</td>
<td>397,400</td>
</tr>
<tr>
<td>Sierra Leone</td>
<td>65,000</td>
</tr>
<tr>
<td>Togo</td>
<td>467,570</td>
</tr>
<tr>
<td>Total</td>
<td>12,897,655</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Countries</strong></th>
<th><strong>Pig populations</strong></th>
<th><strong>Pig populations at risk</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Angola</td>
<td>2,874,400</td>
<td>2,546,849</td>
</tr>
<tr>
<td>Burundi</td>
<td>479,197</td>
<td>391,525</td>
</tr>
<tr>
<td>Cameroon</td>
<td>1,800,000</td>
<td>1,600,984</td>
</tr>
<tr>
<td>CAR</td>
<td>1,000,000</td>
<td>848,251</td>
</tr>
<tr>
<td>Chad</td>
<td>33,500</td>
<td>28,327</td>
</tr>
<tr>
<td>Congo</td>
<td>95,000</td>
<td>79,591</td>
</tr>
<tr>
<td>DRC</td>
<td>991,727</td>
<td>828,616</td>
</tr>
<tr>
<td>Equatorial Guinea</td>
<td>6,800</td>
<td>5,966</td>
</tr>
<tr>
<td>Gabon</td>
<td>220,000</td>
<td>140,315</td>
</tr>
<tr>
<td>Rwanda</td>
<td>1,015,000</td>
<td>878,426</td>
</tr>
<tr>
<td>Sao Tome &amp; P.</td>
<td>35,000</td>
<td>21,275</td>
</tr>
<tr>
<td>South Sudan</td>
<td>14,406</td>
<td>11,217</td>
</tr>
<tr>
<td>Zambia</td>
<td>1,100,000</td>
<td>964,736</td>
</tr>
</tbody>
</table>

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Notes: a FAO estimates in 2017; b Number of pigs calculated by R model; c IGAD, 2015; CAR: Central African Republic; DRC: Democratic Republic of Congo
Pig cysticercosis in West and Central Africa

The number of pig populations at risk of T. solium cysticercosis for each country was calculated based on dominant scavenging and semi-intensive production systems presented in the literature (60–90% of pig populations). Each of the four leading countries in pig production had at least 1,000,000 pigs under systems favoring T. solium. Although published data on T. solium porcine cysticercosis are lacking for some countries, the transmission occurs in all areas where pigs are reared under traditional conditions. For example, no information is available on the pig production of South Sudan in FAO database, but the Inter-governmental Authority on Development (IGAD) estimated in 2015 that the country had 14,406 pigs reared under traditional systems by communities in Upper Nile State, suggesting that T. solium transmission may be occurring between humans and pigs in the country.

Number of pigs infected with T. solium and related financial losses

Based on reported prevalence rates of porcine cysticercosis obtained by tongue palpation and meat inspection in 15 countries of West and Central Africa, the R model estimated the annual number of infected pigs at 6,895,868 (95% CI: 4,262,734–9,881,338), i.e. a prevalence of 30.05% (95% CI: 26.62–43.80). Tables VI and VII show the estimated number of infected pigs and expected prevalence of porcine cysticercosis by country, respectively. Over 90% of the total estimated infected pigs were found in the fifteen countries. Nigeria, Angola, Cameroon, Burkina Faso and Zambia had the highest populations of infected pigs. Visual methods (tongue palpation and meat inspection) estimated 2,384,048 (95% CI: 1,691,797–3,073,781) heavily infected pigs which were not entirely condemned, but marketed at low prices. Financial losses caused by the reduction of the price of infected pigs were estimated at 165 million euros (95% CI: 117,241,510–213,013,030) for the 15 countries. In the case of massive infection, the entire animal was destroyed at the abattoir. This constituted a loss for butchers estimated at 243,935 pigs (95% CI: 121,669–413,172) for the 15 countries (Table VIII). The annual cost related to condemnation and destruction of carcasses for butchers was estimated at 33 million euros (95% CI: 14,500,103–51,113,219). The cost of drugs and indigenous products used by pig farmers trying to prevent reduced prices for their infected animals was estimated at 0.4–1.53€ per pig. The related annual cost of treatment was estimated at 16 million euros (95% CI: 6,896,975–27,672,763) for the 15 countries. The average direct loss for farmers in each country was estimated at 4.5 million euros (95% CI: 3,248,250–5,901,660).
Cysticercose porcine en Afrique de l’Ouest et centrale

the growing demand for meat in urban areas (Porphyre, 2009; Assana et al., 2013), with the plausible subsequent increase of the prevalence of porcine cysticercosis in endemic areas.

The modern pig production systems, which can stop the life cycle of *T. solium*, are not progressing in Africa because of the poor conditions of pig farmers (Kagira et al., 2010). Although great sociocultural, economic, demographic and religious diversities exist in countries of West and Central Africa, variations in pig management systems within the regions are assumed marginal. In addition, similar pig management systems have been reported in countries of Eastern and Southern Africa (Ngowi et al., 2004; Pondja et al., 2010; Thomas et al., 2013) indicating that *T. solium* cysticercosis affects all areas where pigs are reared under traditional systems.

The expected prevalence of 30.05% calculated in our study is similar to that reported by Guyatt and Fèvre (2016). In a recent study, Braae et al. (2015) used a Bayesian framework to estimate and map-informed district-level prevalence of porcine cysticercosis in Africa. A prevalence above 60% that included the results from serological tests was estimated for some districts. Prevalences higher than 60% in these studies might have been overestimated because of cross-reactions between *T. solium* and *T. hydatigena*. Another reason might be the high sensitivity of the serological tests, because in all the studies conducted to date in Africa on porcine cysticercosis, the prevalence in meat and tongue cyst-positive pigs was lower than that in antigen-positive pigs (Guyatt and Fèvre, 2016).

Table VII

<table>
<thead>
<tr>
<th>Countries</th>
<th>Expected true infected pigs</th>
<th>Expected prevalence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Num.</td>
<td>95% CI (%)</td>
</tr>
<tr>
<td>Angola</td>
<td>328,662</td>
<td>267,057–403,218</td>
</tr>
<tr>
<td>Benin</td>
<td>73,722</td>
<td>60,120–89,989</td>
</tr>
<tr>
<td>Burkina Faso</td>
<td>1,262,892</td>
<td>1,071,005–1,467,324</td>
</tr>
<tr>
<td>Burundi</td>
<td>277,864</td>
<td>236,923–320,912</td>
</tr>
<tr>
<td>Cameroon</td>
<td>843,373</td>
<td>708,284–991,436</td>
</tr>
<tr>
<td>Chad</td>
<td>19,647</td>
<td>16,673–22,668</td>
</tr>
<tr>
<td>Cote d’Ivoire</td>
<td>13,756</td>
<td>11,087–17,052</td>
</tr>
<tr>
<td>Gambia</td>
<td>248</td>
<td>192–318</td>
</tr>
<tr>
<td>Ghana</td>
<td>174,696</td>
<td>174,696–211,224</td>
</tr>
<tr>
<td>Nigeria</td>
<td>2,710,800</td>
<td>2,254,888–3,225,081</td>
</tr>
<tr>
<td>Senegal</td>
<td>28,919</td>
<td>23,393–35,684</td>
</tr>
<tr>
<td>Togo</td>
<td>152,875</td>
<td>126,357–183,386</td>
</tr>
<tr>
<td>Rwanda</td>
<td>317,091</td>
<td>262,467–380,562</td>
</tr>
<tr>
<td>Zambia</td>
<td>3,28,524</td>
<td>271,175–395,121</td>
</tr>
</tbody>
</table>

Cl: confidence interval; DRC : Democratic Republic of Congo

Table VIII

<table>
<thead>
<tr>
<th>Infected pigs</th>
<th>Estimated losses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Num.</td>
</tr>
<tr>
<td>Heavily infected seized or destroyed pigs</td>
<td>243,935</td>
</tr>
<tr>
<td>Pig treatment cost</td>
<td>16,307,742</td>
</tr>
</tbody>
</table>

Cl: confidence interval

Studies on the estimated losses caused by porcine cysticercosis in West and Central Africa are scarce. A rough estimation for the two regions using a conservative estimation method (Zoli et al., 2003) and a stochastic approach limited to West Cameroon (Praet et al., 2009) have been reported. Our study is the first to estimate the broader picture of the agricultural burden of *T. solium* cysticercosis in West and Central Africa using Monte Carlo simulations. The results showed that the highest estimated numbers of expected infected pigs and pigs at risk of infection with *T. solium* were mainly in five countries: Nigeria, Angola, Cameroon, Burkina Faso and Zambia. However, a high proportion of infected pigs has been reported in Chad, particularly in the south of the country where people are not Muslim and rear pigs (Assana et al., 2001), as well as in a few communities particularly of the Upper Nile State, in a dominant South Sudan Muslim population rearing pigs (IGAD, 2015). Although Nigeria ranked first in pig production in West and Central Africa (about 4% of the country total domestic livestock population) and with a high prevalence of *T. solium* cysticercosis in pigs, 80% of these pigs are found in non-Muslim areas of the subhumid north, and south Guinea savannah zones of the country (Gweba et al., 2010). These findings suggest that isolated pig rearing communities in predominantly Muslim countries including Northern Africa could be endemic for the zoonosis (*T. solium* cysticercosis in pigs and human taeniasis). Moreover, the number of pigs reared under free roaming/scavenging systems is increasing following the growing demand for meat in urban areas (Porphyre, 2009; Assana et al., 2013), with the plausible subsequent increase of the prevalence of porcine cysticercosis in endemic areas.

The modern pig production systems, which can stop the life cycle of *T. solium*, are not progressing in Africa because of the poor conditions of pig farmers (Kagira et al., 2010). Although great sociocultural, economic, demographic and religious diversities exist in countries of West and Central Africa, variations in pig management systems within the regions are assumed marginal. In addition, similar pig management systems have been reported in countries of Eastern and Southern Africa (Ngowi et al., 2004; Pondja et al., 2010; Thomas et al., 2013) indicating that *T. solium* cysticercosis affects all areas where pigs are reared under traditional systems.

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The direct financial loss caused by porcine cysticercosis estimated by Zoli et al. (2003) at about 25,201,088 € was more than three times lower than that estimated in our study. This difference could be related to the increase in the pig population size in the last decade and the MCMC method used in this study. The mean direct annual loss per country for farmers, traders and butchers in West and Central Africa estimated at 4.4 million euros was higher than 3 million USD of potential loss estimated by Trevisan et al. (2017) in Tanzania in East Africa. The loss is expected to increase following the growing demand for pork in urban areas in West and Central Africa (Porphyre, 2009). A recent study carried out in Zambia to assess the perceptions of the communities regarding pig management showed that confinement of pigs was not seen as an acceptable method to control porcine cysticercosis (Thys et al., 2016). In Burkina Faso, a similar behavior of pig farmers was described. Confinement of animals and construction of latrines are considered too economically constraining by pig farmers (Ngowi et al., 2017). However, they have expressed their willingness to prevent porcine cysticercosis (Ngowi et al., 2017): this disposition could facilitate the adoption of available control tools against this disease. In the past, several attempts have been made to control the disease. The most common actions cited in the literature are community mass chemotherapy, health education, programs to stimulate the use of latrines, improved meat inspection of pigs (Garcia et al., 2006). However, none of these approaches have been very successful. Recently, vaccination of pigs in combination with oxendazole treatment was successful in eliminating *T. solium* transmission in Cameroon, Peru and Nepal (Assana et al., 2010; Garcia et al., 2016; Poudel et al., 2019).

### CONCLUSION

*T. solium* cysticercosis affects pig populations and thus financially affects pig farmers, traders and butchers in West and Central Africa. The public health burden of *T. solium* taeniasis/cysticercosis complex was not assessed, but the high number of estimated infected pigs provided evidence that taeniasis and neurocysticercosis-associated epilepsy in humans are serious health problems in the regions. In a future study, the public health aspect of this zoonosis will be explored. However, the current results emphasize the need to introduce effective and sustainable interventions for managing the health of human and pig populations in the regions. There could be minimal intervention strategies targeting pigs in the endemic areas. Vaccination and treatment of pigs could be the key distribution to reduce indirectly the burden of human taeniasis and neurocysticercosis (Poudel et al., 2019). The endemic countries with the highest pig populations at risk of *T. solium* infection could be targeted in priority.

### Acknowledgments

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### Author contributions statement

EA was the principal investigator. EA, JAN and APZ conceived, designed and coordinated the study. EA and JAN designed R models and carried out the statistical analysis and interpretation. EA, JAN, CAE, ASM, VC, MD and BD participated in the preparation of the manuscript. All authors have read and approved the final version of the manuscript.

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La cysticercose à *Taenia solium* est un problème majeur pour les éleveurs de porcs et représente un risque important pour la santé publique en Afrique. Il y a un intérêt croissant pour éradiquer la cysticercose porcine dans les zones endémiques afin de réduire ou d'éliminer indirectement le téniasis et la neurocysticercose chez les humains. Cependant, les données fiables sur les populations porcines impactées par la cysticercose sont insuffisantes en raison d'un manque d'outils de diagnostic spécifiques. Un modèle stochastique a permis d'estimer les résultats révélant que plus de 16 millions de porcs (intervalle de confiance à 95 % [IC] : 13,7–20,1) étaient maintenus dans des conditions favorables à la cysticercose à *T. solium*. Le nombre de porcs infectés par cette maladie a été estimé à 6,89 millions (IC 95 % : 4,26–9,88), soit une prévalence de 30,0 % (IC 95 % : 26,6–34,8). Les pertes économiques directes pour les éleveurs de porcs et les revendeurs ont été estimées à 165 millions d’euros (IC 95 % : 117,2–133,0). L’étude souligne la nécessité d’informer sur le problème et de mettre en place des mesures de lutte à la fois contre le téniasis et la cysticercose à *T. solium* dans les deux régions.

**Mots-clés** : porcin, cysticercose, *Taenia solium*, modèle de simulation, modèle stochastique, Afrique occidentale, Afrique centrale, Afrique au sud du Sahara