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RAPID COMMUNICATION

First assessment of the prevalence of *Trichinella* in backyard-raised pigs in Central-Southern Chile

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ABSTRACT

Trichinellosis is a significant zoonotic disease worldwide, with pigs as a primary reservoir host of human infection. Backyard pigs are particularly at risk due to their exposure to muscle tissue containing *Trichinella* larvae from synanthropic micromammals or home slaughter waste. In Chile, veterinary inspections of domestically slaughtered pigs are mainly conducted in veterinary clinics using muscle samples provided by farmers or consumers. While positive cases must be reported to the authorities, negative cases are not, creating a gap in official data on *Trichinella* prevalence. This study aimed to assess the prevalence of *Trichinella* sp. in backyard and intensively raised pigs in south-central Chile. Records of 2,608 backyard pigs were obtained from various veterinary clinics in the La Araucanía and Ñuble regions, with a few records from the El Maule and Biobío regions, encompassing a total of 33 communes. The overall prevalence was found to be 0.9% (95% confidence interval: 0.59–1.37). According to the available information, records of more than 50,000 pigs slaughtered in abattoirs per year corresponded to negative results after examination. Previous reports suggest that eradication is challenging; however, the decreasing incidence rate of human infection indicates the possibility of improving control measures for this zoonosis.

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Introduction

Trichinellosis is a globally distributed zoonosis caused by nematodes of the genus *Trichinella* (Korhonen et al. 2016). There are 10 species and three genotypes distributed in two clades (Sharma et al. 2020): one comprising species with encapsulated, and the other with non-encapsulated larvae (Pozio 2021). The most important species for public health is *T. spiralis*, which is the most common in the domestic cycle (Pozio and Murrell 2006). Two typical cycles have been described: the sylvatic cycle, involving wild and feral carnivores and omnivores (Kärssin et al. 2021; Crisóstomo-Jorquera and Landaeta-Aqueveque 2022; Buffoni et al. 2024), and the domestic cycle, involving domestic animals (pigs) and synanthropic mammals. Since pork is a major protein source and one of the most consumed meats worldwide, it is a frequent source of human infection with *Trichinella*, especially from backyard pigs. These pigs can feed on infected hosts, scavenge in garbage dumps, and consume carcasses of slaughtered animals. Rats and scavenging mammals have been proposed as vectors for spreading the infection between farms, rather than for within-farm persistence (Hill et al. 2010; Pozio 2014).

The surveillance of infection in pigs can be performed with various tools. Serological tests such as ELISA can be cost-effective but lack adequate sensitivity and specificity. The gold-standard technique is the artificial digestion of meat with HCl and pepsin, followed by visualization of larvae after sedimentation (Gamble 2022). In contrast, trichinoscopy, which involves compressing muscle samples and visualizing larvae within the capsule, is less sensitive but faster than artificial digestion (Forbes et al. 2003). Successful control requires strict surveillance of backyard or extensively reared pigs, which are most exposed to infection. Intensively raised pigs are rarely infected as they are usually isolated from sources of infection like slaughterhouse waste (Pozio 2014). Industrial farms follow strict biosecurity norms such as: perimeter fence; entry and exit control of people, pigs and materials; feral animal and vector control; laundry; rodiluvium or manual disinfectant aspersion system for vehicle disinfection; facilities must prevent the entry of wild birds or other animals and must be cleanable; there must be cleaning and disinfection procedures or they must be licensed to a specialized company; drinkable water must be potable or sanitized; materials and tools must be of exclusive use of

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the farm and must be disinfected before use; and there must be record of sanitary data such as vaccinations and other medical treatments. The farm must also follow other norms regarding deaths within the fence, the sending of pigs to the abattoir, the management of organic residuals, and emergency plans (SAG 2024)

In Chile, most human infections have been reported in the Central-Southern region, with the highest incidence in the Araucanía Region (Landaeta-Aqueveque et al. 2021), and the sole reported species is *T. spiralis* (Schenone et al. 2002; Landaeta-Aqueveque et al. 2015; Crisóstomo-Jorquera and Landaeta-Aqueveque 2022). Surveillance for *Trichinella* in Chile is mostly performed in abattoirs, which slaughter intensively raised pigs, and the prevalence among those pigs has been previously assessed (Schenone et al. 2002); however, no further report has been published in the last two decades. Conversely, backyard pigs are usually slaughtered and processed at home and their meat can be examined in veterinary clinics. According to current legislation in Chile (MINSAL 2002), both artificial digestion and trichinoscopy are used in abattoirs, which slaughter industrial raised pigs. Meanwhile, trichinoscopy is almost the sole technique used in clinics for examining home-raised pigs, due to its lower cost, fast results and simplicity, and it must be performed by trained veterinary doctors to ensure the reliability of results. Veterinary doctors are obligated to notify authorities of the presence of *Trichinella* larvae in pigs, but not negative results (MINSAL 2018; SAG 2019). This lack of reporting of negative results hinders an accurate assessment of *Trichinella* prevalence in backyard pigs.

Therefore, this study aimed to record both positive and negative results in order to assess the prevalence of *Trichinella* sp. in backyard farms in Central-Southern Chile. This study also estimated the prevalence among intensively raised pigs slaughtered in abattoirs.

Materials and methods

Backyard-raised pigs

Several veterinary clinics offering trichinoscopy services from the Ñuble and La Araucanía regions were surveyed to obtain records of examined pigs, including their communes (smaller administrative geographic units) of origin, and the trichinoscopy result (the presence/absence of encapsulated larvae). These clinics also received samples from the El Maule and Biobío regions; therefore, the study included several localities from these regions as well.

Given the confidential nature of the data, no further information was obtained about the farms where the pigs were raised, beyond the fact that they were small family farms. Neither data on sex nor the age of animals was obtained since, in most cases, these data were not recorded by veterinarians. The animals were slaughtered between 2019 and 2022.

The communes where the animals were raised, as well as the number of animals per commune, are presented in Table 1. To avoid arbitrary bias and to achieve the highest sample size possible, we kept the communes as stated in the records, even when the veterinary doctors informed us that, in some cases, the sample was brought in by the consumer; in those cases, the recorded commune was where the consumer lived and not necessarily where the pig was bred.

Regarding the procedure performed by veterinarians and according to Chilean meat inspection regulations, the standard procedure for trichinoscopy involves cutting seven oat-sized fragments (0.6 – 0.8 g) from one of the diaphragmatic crura, or eight fragments from each of the three samples taken from parts of the carcass, totaling 24 fragments (MINSAL 2002).

Prevalence was estimated following Bush et al. (1997), and the 95% confidence interval (CI) was calculated with binomial distributions following the Clopper-Pearson method using the Quantitative Parasitology platform (http://www.zoologia.hu/qp/qp.html) (Reiczigel et al. 2019). To compare the prevalence between communes with infected pigs, logistic regressions were performed using Stata BE/17

Table 1. Occurrence of *Trichinella* sp. in backyard pigs examined by trichinoscopy in Central and Southern Chile by commune between 2019 and 2022.

Región	Commune	Examined animals	Infected animals; %prevalence (95% confidence interval)
Maule	Chanco	2	0
	Colbún	1	0
	Talca	6	0
Ñuble	Bulnes	8	0
	Chillán	344	0
	Chillán Viejo	111	2; 1.8 (0.2–6.4)
	Cobquecura	1	0
	Coihueco	17	0
	El Carmen	178	4; 2.25 (0.6–5.7)
	Ninhue	2	0
	Ñiquén	2	0
	Pemuco	51	0
	Pinto	25	0
	Portezuelo	7	0
	Quillón	1	0
	Quirihue	1	0
	Ránquil	4	0
	San Carlos	7	0
	San Fabián	2	0
	San Ignacio	128	0
	San Nicolás	50	0
	Yungay	3	0
Biobío	Yumbel	1	0
Araucanía	Chol Chol	1	0
	Cunco	1	0
	Freire	10	0
	Galvarino	1	0
	Imperial	19	0
	Padre Las Casas	22	9; 40.9 (20.7–63.6)
	Perquenco	3	0
	Pitrufquén	1	0
	Temuco	1591	7; 0.44 (0.2–0.9)
	Vilcún	8	2; 25 (3.2–65.1)
Total		2608	24; 0.9% (0.59–1.37)

(StataCorp LLC), and the odds ratio (OR) served as a proxy for the difference in prevalence between communes, since prevalence and ORs are associated with the probability of infection. To enhance the likelihood of finding ORs significantly different from 1, base-level categories were chosen by identifying communes with the highest prevalence. This category and the dummy variables are presented in the Results section. The significance level was $p \leq 0.05$.

Prevalence in abattoirs

We used the governmental transparency system to obtain data on the positive cases, from the Health Ministry (Ministerio de Salud). Since negative cases are not reported and governmental institutions do not have that information, we obtained the total of slaughtered pigs during the studied period from the National Institute of Statistics (Instituto Nacional de Estadísticas – INE) (INE-Araucanía 2024; INE-Ñuble 2024). The data provided by the INE is only available at the region level (several communes together). We also obtained information on slaughtered and infected pigs in an abattoir in the Ñuble Region at the commune level thanks to the collaboration of the Agricultural and Cattle Service (Servicio Agrícola y Ganadero – SAG). Although this data is limited to the year 2023, this information illustrates how the pigs raised in industrial farms are distributed across the region and nearby areas. This data is presented in Table 1.

The study was approved by the Comité de Bioética of the Facultad de Ciencias Veterinarias of the Universidad de Concepción (CBE-01-24).

Results

The records of 2,608 domiciliary slaughtered pigs were obtained from seven veterinary centers in the communes Temuco (4), Chillán (1) and El Carmen (2). Eight of those pigs belonged to the Maule Region, 942 belonged to the Ñuble Region, one to the Biobío Region, and 1,657 to the Araucanía Region. The most represented communes were Temuco, Chillán, El Carmen, San Ignacio, and Chillán Viejo. A total of 24 samples (0.9%; CI: 0.59–1.37) were positive for *Trichinella* larvae. The communes with positive pigs were Padre las Casas ($n = 9$ infected pigs), Temuco ($n = 7$), and Vilcún ($n = 2$) from the La Araucanía region; and El Carmen ($n = 4$) and Chillán Viejo ($n = 2$) from the Ñuble Region. The prevalences and CIs are given in Table 1 and depicted in Figure 1.

The Padre Las Casas commune presented a prevalence that was significantly higher than in Temuco, El Carmen, and Chillán Viejo, and was not significantly different from that of Vilcún (Table 2).

Approximately 28,500 and 27,000 pigs were slaughtered yearly in abattoirs in the Ñuble and Araucanía Region, respectively. Those of the Ñuble region are detailed in the Table 3. According to the information given by the Health institutions, all positive reports belonged only to domiciliary slaughtered pigs, indicating that the prevalence among pigs slaughtered in abattoirs is zero. The diagnostic procedure was not possible to obtain in all cases, but among pigs slaughtered in the Ñuble Region, the diagnosis was made through trichinoscopy.

Discussion

This is the first study of the prevalence of *Trichinella* sp. in home-raised pigs in Chile, with a focus on Central-Southern Chile, which encompasses regions with low and high incidence rates of human trichinellosis (Landaeta-Aqueveque et al. 2021). The results among domiciliary slaughtered pigs showed an overall prevalence of 0.9%, with a range of 0–41% across the examined communes, representing the backyard raised pigs. Conversely, no infected pig was reported among abattoir slaughtered pigs, which represent the intensively raised pigs. A similar study previously performed in Chile more than two decades ago focused only on pigs slaughtered in abattoirs (Schenone et al. 2002); that study reported a 0.04% prevalence. Those pigs were not representative of the pigs from small backyard productions, and, although that study included pigs raised in intensive production, those pigs were bred in less industrialized conditions than in current intensive productions. Given that, in the current study, we found no positive pigs in intensive productions and a prevalence more than 20 times higher than that reported by Schenone et al. (2002) in backyard raised pigs, which suggests that studies were conducted on differently raised pigs, and that the parasite is very much present among backyard raised pigs.

The prevalence of *Trichinella* infection in backyard pigs reported herein is consistent with the values from non-controlled housing conditions reported overseas. For instance, a lower prevalence of 0.2% was reported in Romania (Nicorescu et al. 2015) and in Italy (Sardinia) as well (Bandino et al. 2015); while a similar (within the 95% CI) prevalence of 2% and 1.26% was reported in Argentina (Ribicich et al. 2009) and India (Kalambhe et al. 2024) respectively. The results of indirect detection showed higher values; a seroprevalence of 2.5% was reported in Cambodia (Söderberg et al. 2021), and a very high seroprevalence of 40% was reported in Zaria, Nigeria (Momoh et al. 2013). Thus, reported values of parasite prevalence are usually lower than seroprevalence values, which could result from real higher prevalence in locations using serological techniques, as direct and indirect methods generally exhibit comparable sensitivity (Barlow et al. 2021). Although artificial digestion is the gold-standard diagnostic technique of *Trichinella* larvae, the trichinoscopic examination is the sole technique used by veterinary doctors in Chile for the diagnosis of *Trichinella* sp. in backyard raised pigs, such as a study with artificial digestion with the same sample size is not feasible. A previous study comparing the sensitivity reported a 54%

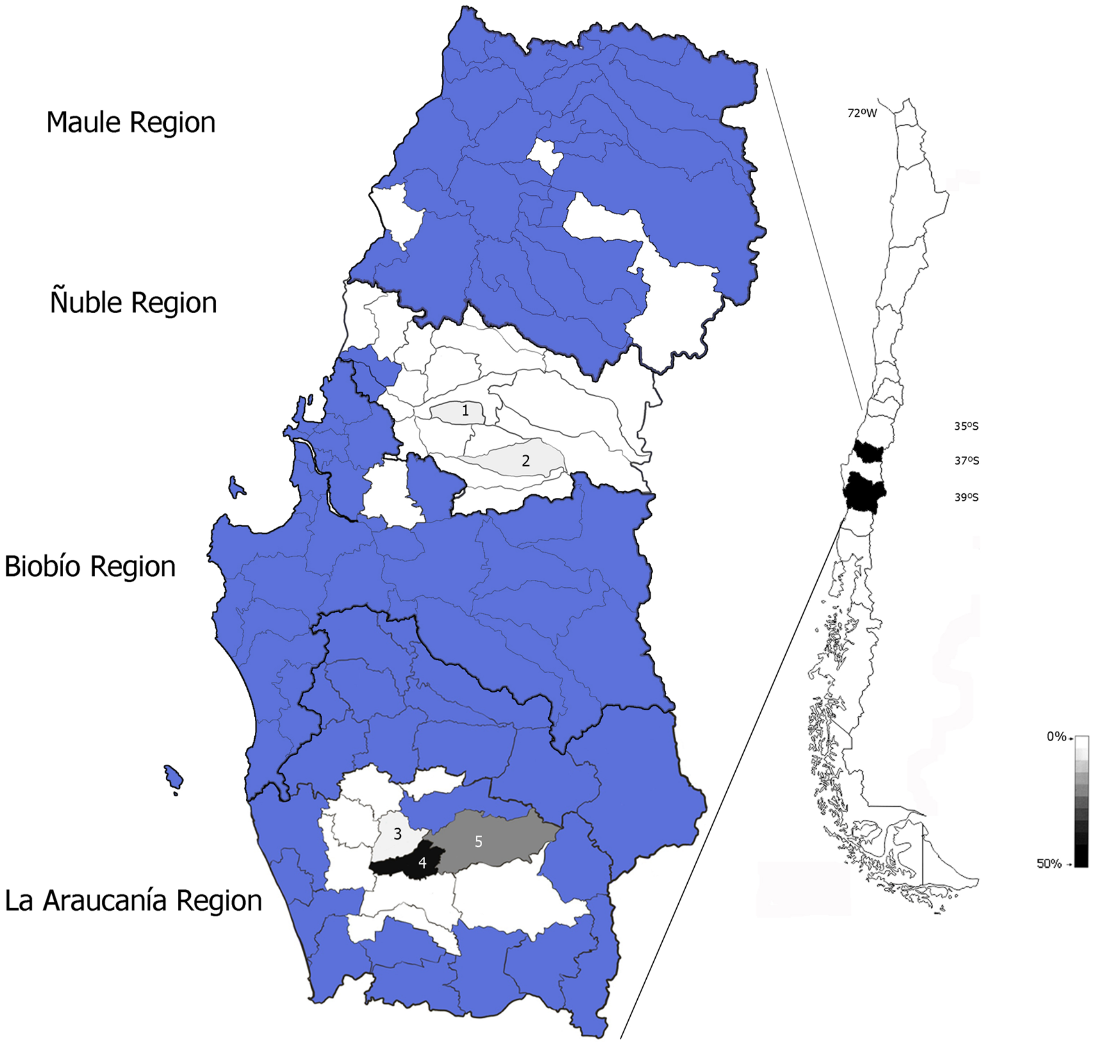

Figure 1. Maps of Chile and the Ñuble and La Araucanía regions in Chile showing the prevalence of *Trichinella* sp. among backyard-raised pigs, which were slaughtered at home and examined *via* trichinoscopy in veterinary clinics from 2019 to 2022. The grey colors represent the prevalence. Blue represents the communes that were not encompassed in this study. The communes with infected pigs and numbered in the figure are (1) Chillán Viejo, (2) El Carmen, (3) Temuco, (4) Padre Las Casas and (5) Vilcún. The map of Chile was modified from d-Maps (https://d-maps.com/carte.php?num_car=181105&lang=es), the maps of the regions were modified from wikipedia (https://es.wikipedia.org/wiki/Chanco, https://es.wikipedia.org/wiki/Regi%C3%B3n_de_%C3%91uble, https://es.wikipedia.org/wiki/Yumbel, https://es.wikipedia.org/wiki/Regi%C3%B3n_de_La_Araucan%C3%ADa).

Table 2. Parameters of the logistic regression model "presence of *Trichinella* sp. = commune". the basal level is the Padre Las Casas commune and the odds ratios are given for each dummy variable.

Commune	Odds ratio	Std. err.	z	P>|z|	95% conf. interval	
Temuco	0.006	0.004	−8.78	<0.001	0.002	0.02
Vilcún	0.481	0.445	−0.79	0.43	0.079	2.948
El Carmen	0.033	0.022	−5.11	<0.001	0.009	0.123
Chillán Viejo	0.026	0.022	−4.35	<0.001	0.005	0.136
β_0	0.692	0.3	−0.85	0.4	0.296	1.62

higher prevalence when using artificial digestion than when using trichinoscopy (80% and 52%, respectively), examining meat from pigs (Forbes et al. 2003), while another found a 43% higher difference when the prevalence is lower (3.35% and 2.35%) (Mohammed et al. 2022). Given the above and extrapolating with the average difference of the

Table 3. Pigs from intensive production farms slaughtered in an abattoir of the Ñuble Region during 2023, by commune. All them were negative.

Región	Commune	Pigs slaughtered in an abattoir
Maule	Colbún	6
	Curicó	151
	Linares	291
	Molina	630
	Parral	30
	Retiro	6
Ñuble	Bulnes	2942
	Chillán	525
	Chillán Viejo	7752
	Coihueco	5011
	El Carmen	10
	Pinto	27
	Quillón	7
	San Carlos	8745
	San Ignacio	2
	San Nicolás	1
Biobío	Los Ángeles	58
Total		26194

previous studies, if the artificial digestion had been performed in Chile instead of trichinoscopy, the observed prevalence could have been approximately 48% higher, i.e. 1.3%. Even if this calculated value could be a little speculative, a certain correction of the underestimated prevalence obtained by trichinoscopic examination might be in order; in addition, the result calculated this way is still similar to that reported in Argentina and India. A field investigation with artificial digestion could assess this correction. It is worth noting that trichinoscopic examination only detects encapsulated larvae, which might pose a limitation for detecting non-encapsulated species. However, since the sole species reported in Chile is *T. spiralis*, which encapsulates, this is not a concern. Another limitation of trichinoscopy is the small sample size analyzed: the standard seven oat-sized fragments amount to less than 1 g, whereas artificial digestion typically examines 1 g of tissue per animal. Although most of Chilean veterinary doctors analyze more than 1 g per animal, and no case of trichinellosis has been reported given the consumption of examined meat, it is advisable to revise Chilean regulations (MINSAL 2002) to align with international standards regarding the amount of tissue analyzed.

Although the main causes of pig infection could include the consumption of infected tissues originating from residual home-slaughter waste, the identification of synanthropic and wild animals infected with *Trichinella* larvae in Central and Southern Chile suggests that it is difficult to eradicate the infection, given that those animals can act as vectors of the parasite between localities, serving as sources of infection after death, either as prey or carrion of synanthropic animals. These animals include rats (*Rattus* spp.), American mink (*Neogale vison*), wild boar (*Sus scrofa*), guiña (*Leopardus guigna*), cougar (*Puma concolor*), and lesser grison (*Galictis cuja*) (Hidalgo et al. 2019; Echeverry et al. 2021a; Echeverry et al. 2021b; Espinoza-Rojas et al. 2021). However, considering that the only species reported in Chile is *T. spiralis*, and that a previous study suggested that the maintenance of this species in nature after the removal of infected pigs is inefficient (Hill et al. 2010), it is feasible to propose that its control is not impossible. Further studies are required to assess the efficacy of control measures, such as confining pigs, controlling rodents, ensuring the sanitary disposal of infected pigs (including burning carcasses) (SAG 2024).

Although this study showed there is a public health risk due to the presence of *Trichinella* sp. in backyard pigs in Chile, it has been noted that the incidence of this infection in humans has been decreasing over time, dropping from 1.9 cases/10^5 inhabitants in 1982 to 0.03 cases/10^5 inhabitants in 2015 (Landaeta-Aqueveque et al. 2021). An acceptable level of knowledge about trichinellosis has been reported in the El Carmen commune, within the studied area, where 40% of respondents correctly answered prevention-related questions, and the average of overall correct response rate was 65% (Lisboa-Navarro et al. 2016). This suggests that, although it is difficult to eradicate the parasite from animal circulation, it is possible to continue reducing the human incidence rate.

The sex-biased infection is an important variable frequently neglected in parasitology (Wesołowska 2022). Sadly, the lack of information about the sex and age of pigs, a frequent situation among domestically slaughtered pigs, prevented us from assessing the association of these variables with the presence of the parasite. A previous study reported sex–biased infection in pigs with higher prevalence among females (2.18%) than males (0.19%) (Mohammed et al. 2022). However, another study in wild mammals reported higher prevalences in brown bear (*Ursus arctos*), grey wolf (*Canis lupus*) and Eurasian lynx (*Lynx lynx*) (Kojola et al. 2017), and an experimental study in rats also reported male sex-biased infection with *T. zimbabwensis* (Hlaka et al. 2015). Although male sex-biased parasitism is the most frequently reported in the literature of the ecology of parasites (e.g. Poulin 1996; Morand et al. 2004; Veloso-Frias et al. 2019), female sex-biased parasitism has also been reported (e.g. Grandón-Ojeda et al. 2022). This suggests that all backyard raised pigs must be considered the same risk until risk factors are appropriately assessed at the most local level.

Padre Las Casas stands out as the commune with the highest prevalence in the studied area. We could not correlate the prevalence with socioeconomical indicators among communes, because we were not able to find detailed statistics per commune (MinDesarrollo 2022). However, it has been reported that Padre Las Casas grapples with significant socioeconomic challenges, these include elevated economic poverty levels and a rural population comprising approximately 40% of its residents (Scuro and Silva 2022). These factors have been suggested to contribute to higher prevalence (Landaeta-Aqueveque et al. 2021), emphasizing the need for new studies, especially in areas with high prevalence such as Padre Las Casas commune. Further research should explore knowledge, attitudes, practices, and risk factors at the community level. This approach could provide valuable insights to design strategies to improve control measures, particularly in communities with the highest incidence rate in humans and prevalence of infection in pigs.

The lack of reports of *Trichinella* infection among intensive raised pigs was expected since those pigs are usually maintained in isolated conditions that better control the most important risk factors for the infections: the consumption of slaughter waste and the predation of rodents. Hence, it has been reported that most of the effort of studying and preventing the infection must be focused on backyard and free-ranging pigs (Pozio 2014).

Finally, considering that (1) previous studies have assessed the presence of *Trichinella* in wild animals, suggesting that they have a minor part in the reservoir; (2) the incidence of human cases has tended to decrease over time; and (3) the recorded absence of *Trichinella* infection in industrialized pigs, it can be concluded that backyard-raised pigs remain the main target of the efforts to control this disease in Chile. However, considering that this is the first study of the prevalence of *Trichinella* infection in these pigs, it is not possible to know the trend of the infection over time nor whether this issue has been addressed adequately. New epidemiological, especially longitudinal studies are needed to assess the trend of the infection, as well as more locally focused studies to identify the factors that favor the presence of the infection among pigs.

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Author contributions

Conception and design: CL-A, JG-F; obtaining data: JG-F, VC-J, AH; analysis and interpretation of the data: JG-F, CL-A; the drafting of the paper: CL-A, AH; revising it critically for intellectual content: VC-J, JG-F; final approval of the version to be published: VC-J, JG-F, AH, CL-A. All authors agree to be accountable for all aspects of the work.

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