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Table of Contents

Pharmacology and Toxicology

Zootechnics

Farm Characteristics and Management Practices Associated with the Detection of *Streptococcus suis* among Smallhold Swine Farms in the Philippines

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Abstract

Background: *Streptococcus suis* is recognized globally as an important zoonotic re/emerging swine pathogen of concern. However, locally situated knowledge regarding this pathogen is severely lacking. **Methods:** In this study, 664 local smallhold swine farms across nine provinces in the Philippines and their management practices were characterized in relation to the presence of *S. suis*. The significant determinants of the presence of *S. suis* were identified by performing binary logistic regression analysis. **Results:** The pen density (odds ratio [OR] = 1.34), the number of sows (OR = 1.30) and boars (OR = 3.15) on the farm, the use of mixed feed sources (OR = 3.16), and the occurrence of pig death within six months prior to sampling (OR = 3.28) were associated with increased likelihood of *S. suis* detection. Showers or hand washing areas (OR = 0.33) and the use of in-feed medication (OR = 0.52) were associated with reduced likelihood of *S. suis* detection. Furthermore, the number of sows on the farm (OR = 1.50) and the farrow- to- finish type of farm operation (OR = 2.06) were associated with increased likelihood of detection of human disease-associated *S. suis* serotypes, while the use of cages/pens was associated with a reduced likelihood of detection of these serotypes (OR = 0.42). **Conclusions:** These findings may potentiate science-based risk assessment and disease prevention strategies for *S. suis* infections.

Keywords: farm management, risk factors, *Streptococcus suis*

1. Introduction

Streptococcus suis, a Gram-positive bacterium, is the most significant streptococcal pathogen affecting swine industries globally [1] *S. suis* is not only a swine pathogen but also an emerging [2] or re-emerging [3] zoonotic pathogen during the last decade, commonly causing sepsis and meningitis [4, 5, 6, 7]. Currently, 29 serotypes of *S. suis* are recognized based on the serological characteristics of the bacterial capsular polysaccharide [8, 9, 10, 11]. Among these serotypes, serotype 2 is most associated with infections in both pigs and humans, however, human infections caused by *S. suis* serotypes 4, 5, 7, 9, 14, 16, 21, 24, and 31 have been documented [12]. While previous studies in other countries have identified the consumption of raw pork dishes as the greatest risk factor, other significant risk factors include pig-related occupations and exposure to pigs and/or pork products [13].

For years, the Philippines has been among the top pork producers worldwide, with an estimated value of approximately PHP 270 billion in 2021 and a pig population of around 10.18 million as of March 2023 [14, 15, 16, 17]. Smallhold farms consistently account for most of the pork production in the Philippines, contributing between 62% and 78% of the total swine inventory annually, spanning from 2000 to 2023 [16]. However, this farm type is susceptible to significant losses due to the limited practice of biosecurity measures such as vaccination, footbath provision, perimeter fencing, rodent control, and swill feeding management [18].

Despite having a substantial pig farming industry, the Philippines has been recognized as a gap in information regarding *S. suis* within the Asian context [19]. This knowledge gap is critical considering the growing number of reported cases of human *S. suis* infections in the country [20, 21, 6, 13, 22, 23, 24, 25]. Notably, between 47% to 60% of the animal meat consumed by Filipinos comes from pork [17].

In a previous study, a national baseline knowledge on the characteristics of locally circulating strains among smallhold swine farms, particularly the serotypes, virulence gene profiles, and multi-locus sequence types, was established, which highlighted the differences between what was observed under local conditions and those that were previously reported in other countries [26].

To provide an initial scientific understanding of the presence of *S. suis* on farms, which may enable risk assessment and disease prevention strategies, the current study characterized local smallhold swine farms and their management practices, and the factors associated with the detection of *S. suis* were identified.

2. Materials and Methods

Smallhold swine farms were sampled following a multistage stratified random sampling approach, as previously described [26]. Briefly, the minimum number of farms to be sampled based on Cochran's method was determined to be 648 considering an assumed prevalence (P) of 0.3, a confidence level (1- α) of 95%, a margin of error (α) of 0.05, and a design effect (DE) of 2.0 [26, 27]. Using data from the Philippine Statistics Authority's swine inventory as of the first quarter of 2019 [28], provinces with high population of pigs in backyard farms were identified. From these, three provinces each were randomly selected from Luzon, Visayas, and Mindanao. For Luzon, the selected provinces were Marinduque, Albay, and Batangas; for Visayas, they were Iloilo, Bohol, and Cebu; and for Mindanao, the provinces were Misamis Occidental, Zamboanga del Norte, and Misamis Oriental. Within these provinces, three barangays with at least 24 smallhold farms were randomly chosen, and from each barangay, 24 households or backyard farms were selected at random. A smallhold farm or a backyard farm was defined as "any farm or household raising any of the following conditions: a) 1 – 20 heads of adult and zero young; b) 1 – 40 heads of young animals; c) 1 – 9 heads adult and 21 heads of young animals," following the definitions set by the Department of Agriculture Bureau of Agriculture and Fisheries Standards (PNS/ BAFS 267:2019) [29], which was similar to the definition used by the Philippine Statistics Authority until its adoption of the revised definitions in 2023 [30]. A survey was conducted among 664 farm owners to gather information on farm characteristics and management practices. The survey and sampling collections were performed from March 2021 to October 2022.

The collection of oral swab samples from 1,567 pigs, and the detection of *S. suis* from these samples were performed as previously described [26]. Binary logistic regression analysis was performed for model building to determine farm characteristics and management practices that could influence the likelihood of *S. suis* detection among the farms sampled. The dependent variable was the detection *S. suis* (coded as 1 for detection and 0 for non-detection). The independent variables considered for inclusion in the model included farm location (Luzon, Visayas, Mindanao), farm characteristics (Table 1), operational biosecurity measures (Table 2), structural biosecurity measures (Table 3), and farm health history and related management practices (Table 4). To construct and refine the model, a stepwise selection method was employed.

Variables were included in the model based on a significance level of $p < 0.05$ and were removed if this criterion is not met. Multicollinearity among independent variables was assessed using the Variance Inflation Factor (VIF). The VIF values for the variables included in the final model ranged from 1.02 to 1.32, indicating minimal multicollinearity and ensuring the reliability of the coefficient estimates Additionally, a separate binary logistic model was constructed to identify factors that may influence the detection of human disease-associated *S. suis* serotypes, which are serotypes 4, 5, 7, 9, 14, 16, 21, 24, and 31 [12, 31]. Multicollinearity was similarly assessed, and VIF values for the variables included in the final model ranged from 1.01 to 1.04. All statistical analyses were conducted using jamovi version 2.3.28 [32].

Results

3.1 Farm Characteristics

A total of 664 farms were included as respondents in this study. The majority of farms (64.91%) raised pigs primarily for profit. In terms of operation, 33.89% of the farms are weaner-to-finish farms, 34.79% as farrow- to-weaner farms, and 30.87% as farrow-to- finish farms (Table 1). The main source of animals was existing breeder sows on the farm (52.86%), while 44.13% of farms relied solely on purchasing animals from neighboring farms or other barangay/s. No information on the exact breeds or strains of the pigs was provided during the survey, as most were locally bred from similarly unknown lineage and were therefore all considered hybrids. Of the farms sampled, 56.02% followed a continuous flow system, while 44.98% followed an all-in/all-out (AI/AO) flow system. Based on observation, a continuous flow system is typically implemented on farms that raise sows, and AI/AO is implemented on farms that do not raise sows. It is also important to note that majority of the pig farms (74.40%) reported no downtime between batches of pigs.

In terms of housing, 72.89% of the farm respondents house pigs in pens constructed using cement, wood, and/or steel; 15.66% tether pigs to trees, posts, or sometimes even the main house; 4.82% follow a free-ranging system, and 6.63% employ a combination of housing systems (Table 1). A free-ranging system, in this case, is described as a farm management approach where pigs are permitted to roam around freely within the perimeter of the farm. However, on some farms, pigs were also allowed to scavenge freely outside the perimeter, indicating that the animals had access to water from the drain, wastewater accumulation around the area, or nearby bodies of water.

Farms that employ a combination of systems, mostly referred to those where boars and sows were tethered but piglets were free ranging. Notably, more farms house pigs in pens in more urban areas such as Batangas, Albay, Cebu, and Iloilo, than farms in Marinduque, Bohol, Zamboanga del Norte, Misamis Occidental, and Misamis Oriental.

One possible explanation for this is that the land area dedicated to agriculture is smaller in these more densely populated provinces. The greater problem is that biosecurity measures are more difficult to implement on free-range farms, as documented in this research. For example, separating clean from dirty areas by building fences is more difficult for farms located in rural areas, especially those situated in sloped areas.

3.2 Operational biosecurity

Operational biosecurity refers to processes and procedures followed during normal day-to-day operations such as population control, health examination, and sanitary practices, etc. [33]. Among the farms surveyed, as presented in Table 2, approximately 95.33% of the farms reported cleaning the pigs and surrounding areas daily; 1.05% on an alternate- day basis; and 0.15% weekly, but only 17.17% used disinfectants such as detergents and chlorine to clean the pens or surrounding areas. Manure management practices differed from farm to farm and depended on farm size. Approximately 58.28% reported using a deep-pit storage system for collected manure. Larger backyard farms, most common in Batangas, have septic tanks for disposal, whereas smaller farms

Table 1. Characteristics of the 664 smallhold swine farms randomly selected from nine provinces in the Philippines.

Characteristics		Frequency	Percent
Type of Farm Operation	Farrow-to-finish farms	201	30.27
	Farrow-to-weaner farms	231	34.79
	Weaner-to-finish farms	225	33.89
	Boar farms	7	1.05
Source of Animals	Bred within the farm only	351	52.86
	Bred and bought	20	3.01
	Bought outside the farm only	293	44.13
Pig Flow System	Continuous	372	56.02
	All–in/all–out	292	43.98
Type of Animal Housing Systems	Free-ranging	32	4.82
	Tied/tethered	104	15.66
	Caged/Pen	484	72.89
	Combination of different housing types	44	6.63

dispose of manure by dumping it in open pits. On the other hand, about 20.93% reported or were collecting manure in a pile close to the pen. In some cases, collected manure is directly disposed of by using it as fertilizer in the gardens. The remaining 20.78% of farms, particularly those that are close to bodies of water (e.g., streams, rivers, or seas), use water and dispose the manure as slurry (Table 2).

Three different types of feeding practices were identified (Table 2). Approximately 82.53% of respondents used only commercial feeds, 5.57% reported using homemade/alternative feeds for their pigs, and the remaining 11.90% used a combination of alternative and commercial feeds. Farms that only use homemade/alternative feeds utilize rice bran, banana leaves, camote tubers, taro, and/or other agricultural byproducts. On the other hand, farms that combine commercial and alternative feeds are those that are more inclined to use table scraps as feeds for their pigs.

More than half of the farm respondents (55.27%) incorporated supplements or antibiotics into the feed or water of their animals (Table 2). The type of medication or supplements administered was not directly observed during the sampling collection and was based only on the self-reports of the respondents. It is also important to note that respondents did not record and/or could not identify the specific medication or supplement administered to the animals. In most cases, respondents claimed to have relied on what was provided by the regional or provincial veterinarian or recommendations from local drugstores.

Most farms (51.81%;) keep pigs by age group in separate pens, but only 25.60% implement downtime, a period when pens or farms remain unoccupied. Only 38.25% limit farm access to farmers and farm owners, and 68.98% raise pets like dogs and cats, chickens and other animals that often come into contact with the pigs (Table 2). Based on our observations, chickens and other poultry species are more commonly and frequently in contact with pigs. Some farms even put chicken coops around or inside the pig pens.

3.3 Structural Biosecurity

Structural biosecurity practices refer to practices that introduce barriers to prevent the entry of infectious agents [33]. These include establishing designated areas for showering or handwashing, installing foot baths or boot dipping stations, and putting up quarantine areas, and fences or nets to prevent other animals from accessing the pig area.

Table 2. Operational biosecurity measures employed on the 664 swine farms randomly selected from nine provinces in the Philippines as reported by respondents.

Characteristics		Frequency	Percent
Cleaning Schedule	Every day	633	95.33
	Every other day	7	1.05
	Once a week	1	0.15
	Never	23	3.46
Cleaning Material	Water and disinfectant	114	17.17
	Water only	550	82.83
Swine Manure Management	Collected	387	58.28
	Flushed	138	20.78
	Thrown	139	20.93
Disposal of Dead Pigs	Disposing in an open area	4	0.60
	Burning	5	0.75
	Burying	655	98.64
Feed resources used by smallholder pig farmers	Homemade/Alternative feeds	37	5.57
	Commercial feeds	548	82.53
	Homemade/Alternative and commercial feeds	79	11.90
In-water or in-feed medications/supplements	Yes	367	55.27
	No	297	44.73
Separate Pen for other Age Groups	Yes	344	51.81
	No	320	48.19
Downtime between batches	Yes	170	25.60
	No	494	74.40
Washing between batches	Yes	179	26.96
	No	485	73.04
People access to the farm (apart from the farm workers)	Yes	254	38.25
	No	410	61.75
Other animal access to the farm	Yes	458	68.98
	No	206	31.02

Less than a quarter of farms were observed to implement structural biosecurity practices (Table 3). Only 24.70% installed fences or nets to prevent other animals from accessing the pig area, 20.78% designated quarantine areas for new incoming and/or sick pigs, 13.86% had functional showers and/or handwashing areas, 6.48% reported changing or designating a specific set of clothes for when in contact with the pigs, and 5.12% had installed foot baths and/ or boot dipping stations.

3.4 Farm Health History

Most farms (85.54%) reported no observed disease or infection, and 73.04% reported no mortalities in the six months leading up to sampling collection (Table 4). However, some respondents seemed hesitant to disclose information about the health status of their pigs. This hesitancy is likely linked to concerns about potential financial repercussions, particularly following the culling of infected and high-risk animals due to the detection of African Swine

Table 3. Structural biosecurity measures employed on the 664 swine farms randomly selected from nine provinces in the Philippines as reported by respondents.

Characteristics		Frequency	Percent
Presence of fences or nets (to keep other animals away)	Yes	164	24.70
	No	500	75.30
Presence of functional showers and/or handwashing areas	Yes	92	13.86
	No	572	86.14
Presence of foot baths and/or boot dipping stations	Yes	34	5.12
	No	630	94.88
Change of clothing (before and/or after contact with pigs)	Yes	43	6.48
	No	621	93.52
Quarantine areas (for new incoming and/or sick pigs)	Yes	138	20.78
	No	526	79.22

Fever (ASF), which resulted in significant economic losses for small-scale operations with limited resources. The lack of immediate visible benefits, such as compensation or support, may have further discouraged reporting.

Less than half (45.78%) of the farm respondents reported vaccinating the pigs, and 75.60% were aware of the appropriate channels for reporting pig sickness, mortality, and other related emergencies (Table 4). However, it is also noted that some respondents believe that reporting is not at all necessary for small-scale operations.

3.5 Farm characteristics associated with the detection of *S. suis*

Employing logistic regression analysis, several farm-level characteristics and management practices showed significant associations ($p < 0.05$) with the detection of the *S. suis* (Table 5).

The results showed that the detection of *S. suis* is associated with several farm-level factors, including pen density (number of pigs per pen area), the number of sows and boars on the farm,

Table 4. Observed diseases and related management practices on the 664 swine farms randomly selected from nine provinces in the Philippines as reported by respondents.

Characteristics		Frequency	Percent
Reported disease history (Enteric, Respiratory, Central Nervous System)	One type of disease	91	13.70
	Two types of diseases	5	0.75
	None	568	85.54
Vaccination of pigs	Yes	304	45.78
	No	360	54.22
Know where to report in case of pig sickness/death	Yes	502	75.60
	No	162	24.40
Presence of pig death within 6 months prior to sampling	Yes	179	26.96
	No	485	73.04

Table 5. Estimated logistic regression model of the risk factors associated with detection of Streptococcus suis in pigs on the 664 swine farms randomly selected from nine provinces in the Philippines.

Factor	Estimate	95% Confidence Interval		p-value*	Odds ratio
		Lower	Upper		
Intercept	-2.538	0.0444	0.141	< .001	0.0791
Farm Characteristics					
Pen density	0.293	1.1255	1.596	0 .001	1.3402
Number of sows on a farm	0.266	1.0470	1.626	0.018	1.3048
Number of boars on a farm	1.147	1.2214	8.124	0.018	3.1500
Farm Management Practices					
Presence of showers or hand washing areas in the farm [a]	-1.123	0.1326	0.798	0.014	0.3253
Using mixed sources of feed (i.e. both commercial and alternative sources) [b]	1.149	1.3272	7.504	0.009	3.1558
Using in-feed medication (i.e. supplements, antibiotics, or both) [a]	-0.653	0.2977	0.910	0.022	0.5205
Farm Health History					
Presence of pig death within six (6) months before the sampling collection [a]	1.188	1.7059	6.307	< .001	3.2801

[a] Absence as the reference category; [b] Not using a mixed source of feed as the reference category; *significant at $p < 0.05$

the presence of showers or hand washing areas on the farm, the use of a mixed source of feed and in-feed medication, and the presence of pig death within six months before sampling (Table 5). On average, the detection of *S. suis* is increased by 34%, and 30% for every additional increase in the pen density and number of sows, respectively, on the farm. Of particular importance, the results also revealed that there was a 3.15-fold increase in the percentage of *S. suis* associated with each additional increase in the number of boars on the farm, while all the other factors remained constant. It was also determined that the presence of showers or hand washing areas, and the use of in-feed medications reduce the likelihood of *S. suis* detection by about 67% and 48%, respectively. Moreover, farms using mixed feed sources are 3.16 times more likely to be positive for *S. suis* than farms that exclusively use either homemade/alternative feed or commercial feed. In addition, the occurrence of pig death on the farm within six months before the sample collection was also found to be a significant influential factor, with 3.28-fold greater likelihood of *S. suis* detection compared to farms with no reported pig deaths.

4. Discussion

Previous studies have shown that *S. suis* is usually more frequently detected in sows and piglets than in other age groups, possibly because of the long contact time between piglets and sows, further emphasizing the need to pay more attention to the sows [34]. This is particularly important since sows are kept on farms longer, thus increasing the possibility of being exposed to and carrying multiple strains of the pathogen, especially if there are new introductions to the population. Similar to sows, boars are also kept longer on farms. It can be hypothesized that boars may also host multiple strains of the pathogen acquired from other farms.

Boars are typically rented for breeding services and are usually transported to other farms, creating opportunities for exposure to different pathogens, including different strains of *S. suis*, which may be introduced back to the resident population of the home farm. The reasons above may also explain why farrow-to- finish farms were found to be associated with higher likelihood of positive detection of human disease-associated *S. suis* serotypes.

Three factors associated with the likelihood of detecting human disease- associated serotypes of *S. suis* among the sampled smallhold farms in the Philippines were found to be significant (Table 6). These factors are the farm operation type being farrow-to-finish, number of sows on a farm was also found to be associated with, on average, a 52% increased likelihood of detecting human disease-associated serotypes of *S. suis* for every increase in the number of sows, while the use of cages or pens on a farm was associated with an almost 60% reduction in human disease-associated serotypes of *S. suis* (Table 6).

Table 6. Estimated logistic regression model of the risk factors associated with the detection of human disease-associated Streptococcus suis serotypes in pigs on the 664 swine farms randomly selected from

Factor	Estimate	95% Confidence Interval		p-value*	Odds ratio
		Lower	Upper		
Intercept	-2.790	0.0331	0.114	< .001	0.0614
Farm Characteristics					
Farrow-to-finish farm [a]	0.722	1.0645	3.981	0.032	2.0587
Number of sows on a farm	0.417	1.2309	1.871	< .001	1.5176
Farm Management Practices					
Caged/Pen [b]	-0.877	0.2111	0.819	0.011	0.4159

[a] Not farrow-to-finish farm as the reference category [b] Absence as the reference category; *significant at $p < 0.05$

Notably, pig flow system was not found influential to the detection of *S. suis*. While it has been previously suggested that the all-in/all- out flow system may be beneficial in controlling *S. suis* [1], to the best of our knowledge, no published studies positively demonstrated an association between this pig flow system and *S. suis* infection or disease. Given the conditions observed among smallhold farms sampled in this study, it may be hypothesized that while farms may implement the all-in/all-out flow system, the presence of sows and boars in the farm may have more significant contribution to the positive detection of *S. suis*, since sows and boars may serve as reservoirs and/or carriers, as explained above. Furthermore, since *S. suis* has been shown to have longer viability when protected by manure and is transmissible via fomites (such as manure-covered boots) [1, 35], it can be additionally hypothesized that controlling the pathogen's transmission within the farm may not be sufficient with an all-in/all- out flow system alone, when other factors, such as fomites, are not managed.

On the other hand, consistent with earlier research results, housing a large number of pigs within a single enclosure can increase the potential for direct nose-to-nose interactions among pigs, which is one of the routes for the horizontal transmission of *S. suis* [36]. It can also induce physiological stress, which in turn can disrupt the immune system of the pigs, thereby enhancing their predisposition to infection [37]. This, coupled with limited movement and poor ventilation, can lead to poor air quality, which can further impair the welfare, health, and growth of the animals [38]. Furthermore, the recorded occurrence of mortality on a farm before sampling likely indicates the general health status of the farm, and thus the observed association with the presence of *S. suis* infection.

On the other hand, the exclusive use of either commercial feed or alternative feed sources, as opposed to the use of a combination of sources of feedstuff, is associated with a decreased risk of the presence of *S. suis* infections. One possible explanation is that farms that exclusively use homemade or alternative feed sources are those that prepare feeds using agricultural byproducts, while farms that use a combination of commercial and alternative feedstuffs are those that are more inclined to include table scraps or food waste (i.e. swill feeding). This practice potentially introduces a wide range of disease-causing pathogens, including those responsible for diseases, such as African swine fever (ASF), classical swine fever (CSF), foot-and-mouth disease (FMD), porcine reproductive and respiratory syndrome (PRRS), and hepatitis E virus [18, 39, 40].

The current study also showed that in-feed medications and supplements are associated with a decreased likelihood of *S. suis* detection. This could be attributed to proper nutrition, which is essential for the optimal growth and development of pigs, making them more resilient to diseases and helping them recover more quickly if they become sick. Some in-feed medications may also include antimicrobial agents or growth promoters that can help control and prevent infection. Lastly, putting up designated showers or handwashing stations inside the farm is also associated with a decreased risk of the presence of *S. suis* infections. These measures have been previously shown to reduce the potential for farm workers or visitors to act as carriers of pathogens [41].

5. Conclusions

Taken together, the findings of this study suggest that the detection, surveillance, and monitoring of *S. suis* infection and carriage among sows and boars on farms may provide essential information on the circulating strains of *S. suis* on farms that may aid in risk assessment and management efforts. This is particularly important since during parturition, vertical transmission of *S. suis* from carrier sows to infants occur upon contact of the sow's vaginal secretions with the piglet's oral cavity and the pathogen colonizes the piglet's tonsil soon after birth [3]. Furthermore, the practice of several biosecurity measures, including securing uncontaminated sources of feedstuff and the addition of in-feed medication or supplements, as well as the use of handwashing/showers, and cages/pens may help control *S. suis* infections, thereby promoting animal health and wealth and reducing the risk of potential zoonotic human infections.

Availability of Data and Materials

The data collected during the course of this research are already included as part of the submitted manuscript.

Author Contributions

Conceptualization, S.A.S, N.A.T. and B.B.I.S; Methodology, S.A.S, N.A.T. and B.B.I.S; Investigation M.G.C.T.C, and A.M.E.S.dG. Formal analysis, N.A.T. and B.B.I.S.; Writing- Original Draft, B.B.I.S., A.M.E.S.dG., and M.G.C.T.C; Writing - Review and editing, S.A.S., N.A.T, and M.A.C.E; Project Funding acquisition, S.A.S., B.B.I.S, and M.A.C.E. Project Administration and Supervision, SAS; All authors approved the submitted manuscript.

Ethics Approval and Consent to Participate

Pursuant to the provisions of RA 8485 or the Animal Welfare Act, Animal Research Permit with reference No. AR-2021-018 is given by the Bureau of Animal Industry for this study and UPLB IACUC Approval number (BIOTECH- 2021-001). No human ethics approval was obtained since the study was conducted prior to the accreditation of UPLB Research Ethics Committee in September 2022.

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Conflict of Interest

The authors declare no conflict of interest.

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