Research Article

Factors Influencing Biosecurity Adoption and Its Limited Economic Impact on Smallholder Swine Farms

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Abstract | Biosecurity is globally recognized as a fundamental measure to prevent infectious disease transmission at the farm level. This study surveyed 360 smallholder swine farmers across Trà Vinh, Long An, and Bến Tre provinces to examine their sociodemographic characteristics, biosecurity management (BM) practices, attitudes toward BM, and production performance. It further assessed how socioeconomic and psychological factors influence BM status and how BM affects economic sustainability. Descriptive statistics, multiple linear regression, and logistic regression analyses were explored all the relationships. The results indicated that farmers were more inclined to implement and adjust biosecurity measures than to plan or monitor biosecurity practices. Adjusting the biosecurity plan accounted for the highest proportion (65.32%), whereas planning was the lowest (51.08%). In terms of attitudes, 69.2% of respondents expressed interest in adopting BM, and only 47.2% believed that biosecurity practices accepted by community. The factors, including age, gender, occupation, farming experience, household size, and farm scale, were found to significantly influence the adoption of biosecurity management practices. Furthermore, no significant relationship was observed between biosecurity management (BM) practices and production efficiency (B= -0.028, p =0.185). Overall, the results suggest that although biosecurity management (BM) is essential for maintaining herd health and enhancing long-term resilience, its economic benefits are not automatically realized among smallholder swine farmers. This finding implies that policymakers should provide greater support to smallholders through financial incentives, technical training, and cooperative disease surveillance programs aimed at reducing the costs and increasing the perceived value of BM adoption.

Keywords | Biosecurity management, Swine farm, Attitude, Mekong delta, Social demographics

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INTRODUCTION

The swine farming industry is one of the developed sectors in Vietnam. As of February 2024, the national swine population had increased by 4.8% compared to the same period in 2023, while the poultry population rose by 2.1% (GSO, 2024). Despite being a major global producer of swine, Vietnam has faced persistent challenges in controlling the spread of highly contagious diseases. The first outbreak of African Swine Fever (ASF) in the country was reported in February 2019 in Hung Yen Province (Le et al., 2019). Additionally, outbreaks of infectious diseases

such as highly pathogenic avian influenza in poultry (Islam *et al*., 2024) and classical swine fever in swine (Ukita *et al*., 2024) have been largely attributed to deficiencies in farm biosecurity practices. Therefore, biosecurity was considered for the prevention of swine disease in Vietnam. Implementing biosecurity management (BM) is recognized as an effective strategy for controlling farm-level disease outbreaks (Kouam *et al*., 2020). Similarly, Jiang *et al*. (2022) emphasized that biosecurity remains the most reliable approach for preventing and mitigating African Swine Fever (ASF) outbreaks. However, Lee *et al*. (2021) argued that weak biosecurity practices among smallholder farms were a major contributing factor to the rapid nationwide spread of the disease, leading to substantial economic losses for the swine industry. In Vietnam, smallholder swine farms account for a large proportion of total production but are generally characterized by low biosecurity standards. Barriers to adopting effective biosecurity measures persist, particularly among traditional smallholders, primarily due to limited financial capacity to invest in adequate biosecurity infrastructure (Nguyen-Thi *et al*., 2021). According to Cuc *et al*. (2020), there are many reasons for the difficulties in implementing biosecurity, such as management, geographical conditions, small-scale farming systems, and limited knowledge of farmers. Futhermore, attitudes and factors intrinsic to the farmer appear to affect how likely farmers are to undertake biosecurity measures related to the prevention of specific disease transmission routes (Richen et al., 2018). Furthermore, previous research suggests that socioeconomic factors, such as gender, education, and income, significantly influence farmers' adoption of biosecurity practices (Beharielal *et al*., 2022; Oliveira *et al*., 2018; Ritter *et al*., 2017). These factors can impact farmers' perceptions of risk, their willingness to invest in preventive measures, and their ability to implement effective biosecurity protocols (Qui *et al*., 2024; Mbanda-Obura *et al*., 2017).

From these challenges in Vietnam, it is essential to further investigate the factors that influence the adoption of biosecurity practices. Thus, the study investigates the status of biosecurity management and the relationship between socio-demographic characteristics, attitude and biosecurity management on smallholder swine farms. Besides, Ziebe *et al*. (2025) stated that biosecurity plays a crucial role in improving poultry performance and reducing antimicrobial use. Previous studies have demonstrated that farms with high biosecurity standards exhibit improved feed conversion ratios, reduced mortality, and greater overall production efficiency due to the lower prevalence of endemic and emerging diseases (Alarcón *et al*., 2021). Despite this, adoption levels and compliance vary globally, especially in developing regions where resource limitations and knowledge gaps hinder consistent implementation (Buckel *et al*., 2024). The previous study (Fakudze et al., 2021) stated that experience, access to market information, access to extension services, target market were the significant factors that affect profitability of swine producers. Therefore, this study aims to enhance understanding of how biosecurity management practices affect the economic outcomes and sustainability of smallholder swine production systems. The findings are expected to contribute to the existing body of knowledge on biosecurity management and its practical implications. Moreover, the results may provide valuable insights for policymakers, enabling them to design and implement more effective biosecurity policies that support smallholder farmers in the Mekong Delta. While smallholder poultry farmers in Ghana were aware of the importance of biosecurity practices, they struggled with consistent implementation.

MATERIALS AND METHODS

Time and location

The study was conducted in three provinces of the Mekong Delta, located in southern Vietnam. Tra Vinh, Ben Tre, and Long An were selected because of their relatively large swine populations and frequent occurrence of infectious disease outbreaks, making them representative areas for studying biosecurity management in smallholder pig farming systems. In addition, their geographical position along the main transportation routes to Ho Chi Minh City, the largest livestock market in southern Vietnam, contributes to high levels of animal movement and associated challenges in disease prevention and control. The field survey and data collection were carried out between January and June 2024, covering both the dry and early rainy seasons, which allowed for the observation of seasonal variations in farm activities and biosecurity practices.

Data collection

The target respondents of this study comprised smallholder swine farmers, who often face challenges related to infectious disease outbreaks in their herds. As the total number of smallholder pig farmers in the study area was not available, a non-probability sampling approach was employed to select respondents. The research locations were selected based on the purpose of sampling. According to Levine and Stephan (2010), for an unknown population, a minimum sample size of 30 respondents is considered sufficiently large to ensure reliable analysis. Based on this guideline, the present study selected four districts from each province, and within each district, 30 respondents were chosen. Consequently, a total of 120 respondents were surveyed per province, ensuring an adequate and representative sample size. In total, 360 swine farmers were interviewed across the three provinces.

The selection criteria for respondents were as follows: farmers were required to own at least 10 swine units on their farm, in accordance with Decree No. 13/2020/ND-CP of Vietnam (FAO, 2024), and to have a minimum of one year of experience in swine production. In addition, to ensure that respondents were knowledgeable about biosecurity, only farmers who had received training related to the national regulations on swine farm biosecurity standards (QCVN 01-14:2010/BNNPTNT) were included in the survey. These criteria were established to ensure that the selected participants were representative of the target population. The questionnaire was initially developed in English and then translated into Vietnamese including five sections.

- Section 1: The respondents were asked about their socio-demographic characteristics (i.e. age, gender, education, occupation, experience, family member, labor, farm size, and income will be collected, which are collected following in Table 1.
- Section 2: This study was intended to conceptualize biosecurity management (BM) as a dynamic, continuous management process rather than a static set of practices. Therefor, the BM measures were categorized into four key components as described by Carlos (1993): planning, implementation, control, and adjustment. According this approach offers an integrative perspective in management biosecurity acitvities that captures behavioral in managedimensions of biosecurity activities, which are often underrepresented in biosecurity practices disease-specific biosecurity scoring tools used in other studies. Based on the conceptual frameworks of previous studies, the statements under each category were developed, including planning (6 statements), implementation (4 statements), control (4 statements), and adjustment (5 statements). In total, 19 statements were used to collect scores reflecting the level of biosecurity management practices. Each response was assigned a score of 1 point if the respondent agreed with the statement or performed the action on their farm, and 0 points if they did not.
- Section 3: Farmers were surveyed regarding their attitudes toward implementing biosecurity management (BM) practices. Respondents were asked to rate six statements reflecting their attitude toward applying BM measures on their farms. A five-point Likert scale was used, ranging from 1 (strongly disagree) to 5 (strongly agree).
- Section 4: From an economic perspective, sustainability refers to the efficient use of resources, competitiveness, and viability of the sector (Spicka et al., 2019). Based on this concept, the production efficiency index was chosen as an indicator of the economic sustainability of swine farms. The cost of swine production was also recorded to assess the financial performance of smallholder farms. This included key cost components such as feed, veterinary expenses, breeding stock, utilities, and other operational costs. These data were essential for estimating the production efficiency index and evaluating the overall economic sustainability of the swine production system (Table 2).

Table 1: Definition of socio-demographic characteristics.

No.	Variables	Description
1	Age	Age of the farmers of the year (continuous)
2	Gender	Gender of swine farmers who were chosen as respondents (1= Male, 0= Female).
3	Education	The education of farmers in the school (1= primary school, 2= secondary school, 3= high school, 4= bachelor, 5= graduate)
4	Occupation	The main occupation of farmers (0=otherwise, 1=animal husbandry)
5	Experience	The number of years in swine raising of the farmers (continuous)
6	Family member	The number of members in the family (Continuous)
7	Labor	The number of family members participating in farming activities (Continuous)
8	Farm size	Total lands that farmers used for rasing swine (Continuous)
9	Income	Income that swine farmers earned from raising swine per month (Continuous)

Table 2: The cost of swine production and production efficiency of small-scale swine farmers.

Catagories	Description
Total income	The average income obtained from the sale of all fattening pigs in each production cycle (USD)
Piglet price	Average expenditure on piglet purchases per production cycle (USD)
Feed price	Average expenditure on feed per production cycle.
Veterinary price	Average expenditure on veterinary services per production cycle (USD)
Water-Electricity price	Average expenditure on electricity and water per production cycle (USD)
Production efficiency	The ratio of total income to total cost
Efficiency	A production efficiency ratio of 1 indicating efficiency
Inefficiency	A production efficiency ratio of below 1 indicating inefficiency

Data analysis

In terms of biosecurity management (BM) practices, each item within the four categories was scored as 1 if the respondent applied the practice on their farm, and 0 if not. The adoption rate for each practice was then calculated by dividing the number of farms applying the measure by the total number of farms surveyed, and the result was expressed as a percentage (Kouam *et al*., 2020).

Regarding attitude of farmers toward BM, a five-point Likert scale was used to measure attitude (6 statements) of farmers toward biosecurity management, with scores ranging from a minimum of 6 to a maximum of 30. Notably, the results of the Cronbach's alpha analysis indicated a high level of reliability for each dimension measured, with reliability coefficients of 0.767 for attitude.

The production efficiency was calculated based on the ratio of total income to total cost (Zelenyuk, 2023). The total cost represented the overall expenditure incurred by the farmer during one production cycle, including all expenses listed in Table 2. The computation of production efficiency was carried out using the following equation:

$$\text{Productivity efficient} = \frac{\text{total income}}{\text{total cost}}$$

After identify the production efficiency, the results will convert this into, with a ratio exceeding 1 denoting efficiency and a ratio of 1 or below indicating inefficiency

Data were analyzed using IBM SPSS 26.0 (IBM Corp, Armonk, NY, USA), and statistical significance was determined at a 5% level. Descriptive statistics were used to analyze these socio-demographic characteristics, BM status, the perception and attitude, the financial production, including min, max, mean and frequency.

Multiple linear regression was used to analyze the relationship between a socio-demographic characteristics, attitude characteristics variable and farmers' biosecurity management practices (BM). Statistical significance was determined at $p < 0.05$ or $p < 0.01$. The model is presented in the formulation as follow:

$$Y_{BM} = b_1x_1 + b_2x_2 + \ldots + b_nx_n + c. \text{ Here, } b_i\text{'s } (i = 1, 2\ldots n)$$

Where; Y_{BM} is the BM index is a dependent variable that is the total value of the BM on each farm. x is independent variables including x_1: Age, $x_{2:}$ gender, $x_{3:}$ education, $x_{4:}$ occupation, $x_{5:}$ experience, $x_{6:}$ family member, x_7: labor, x_8: farm size, x_9: income, x_{10}: attitude toward BM.

Logistic regression was employed to analyze the factors influencing economic sustainability. The relationship between biosecurity management practices (BM) and production efficiency (PE) was evaluated. Statistical significance was determined at $p < 0.05$ and $p < 0.01$. The model was formulated as follows:

$$Y_{PE} = b_{BM}x_{BM} + c$$

In which: Y_{PE}: The index of productivity eficientcy; X_{BM}: The status of biosecurity managements practice

RESULTS

Socio-demographic characteristics and the status of biosecurity management of farmers in the Mekong Delta Table 3 shows that the average age of the farmers was 49.7 years, most respondents (76.9%) were male, highlighting that males played an important role in raising swine. Second, the level of education was high, with 46.1%

Table 3: Social-dermo characteristics of small-scale swine farmers (n = 360).

Variables	Categories	N	Result
Age	Min		27
	Max		67
	Mean ± SD		49.70 ± 7.85
Gender (%)	Female	83	23.1
	Male	277	76.9
Education (%)	Primary school	14	3.9
	Secondary	59	16.4
	High school	166	46.1
	Bachelor	94	26.1
	Graduate	27	7.5
Occupation (%)	Others	85	23.6
	Animal husbandry	275	76.4
Experience	Min		2
	Max		37
	Mean ± SD		11.93 ± 7.27
Family member	Min		3
	Max		9
	Mean ± SD		4.38 ± 1.12
Labor	Min		0
	Max		4
	Mean ± SD		1.44 ± 0.65
Farm size (Ha)	Min		0.01
	Max		2.00
	Mean ± SD		0.19 ± 0.27
Income (USD)	Min		40.65
	Max		1219.51
	Mean ± SD		338.71±252.86

graduating from highschool. Most respodents (76.4%) stated that animal husbandry as their main occupation, with over 11.93 years of experience in swine farming. The average family member was high, with 4 members per household and more than one laborer participating in their swine production. The average income reflected limited profitability that the average farm income was just 338.71 USD. Additionally, the average farm size was small, measuring only 0.19 hectares, which may constrain production capacity and income potential.

Regarding biosecurity management (Figure 1), the study found that farmers generally demonstrated strong proficiency in biosecurity implementation (63.32%), while an even higher proportion (65.15%) reported active engagement in biosecurity adjustment practices. Fewer farmers prioritized the planning (51.08%) and control (56.32%) components of biosecurity, suggesting these areas may receive less attention compared to other counterparts.

The attitude of farmers toward biosecurity management

The results presented in Table 4 demonstrate a generally high level of positive attitude among farmers to apply biosecurity measures in swine production, with an overall mean score of 4.09 ± 0.42, indicating strong agreement across the surveyed items. A considerable majority of respondents (69.2%) demonstrated a strong interest in the application of BM, with an additional 28.6% showing very strong agreement, suggesting a willingness to adopt these practices. Similarly, 89.7% of respondents felt adequately informed about BM reflecting effective dissemination of related information. Understanding of BM was also relatively high, with 79.2% reporting good to very good comprehension. However, a limited proportion of participants (20.8%) exhibited only moderate or limited comprehension, underscoring the need to strengthen communication approaches and refine training materials. A majority of respondents (61.1% agree and 20.6% strongly agree) believed that BM is an effective approach to improving swine production. Regarding social acceptance, 47.2% of respondents agreed and 21.4% strongly agreed that biosecurity management activities are accepted by their communities, although nearly one-third (30.3%) remained neutral. Notably, almost all respondents (92.5% agree and strongly agree) supported the promotion of BM among farm households, reflecting strong willingness to encourage wider adoption across the swine sector.

Cost structure and production efficiency of small-scale swine farmers

Table 5 presents the cost components and production efficiency of small-scale swine farmers. The average selling price of fattening swine was 197.96 ± 17.85 USD per head, ranging from 166.79 USD to 250.00 USD. The average price of piglets purchased per cycle was 38.01 ± 9.29 USD, with a range between 22.80 USD and 64.59 USD. Feed costs represented the largest expenditure, averaging 110.51 ± 19.09 USD, and ranged from 72.19 USD to 284.95 USD. Veterinary expenses averaged 30.77 ± 41.20 USD, while water and electricity costs were relatively low, averaging 21.02 ± 14.81 USD.

Table 4: The attitude of farmers toward biosecurity management.

Statements	Degree of perception				
	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I am interested to apply the BM	-	-	2.2	69.2	28.6
I feel well inform about the BM	-	0.3	10.0	63.9	25.8
I undertand the practice of BM	-	0.8	20.0	57.5	21.7
BM was a good way for improving swine production	-	0.3	18.0	61.1	20.6
The BM is accepted by the community		1.1	30.3	47.2	21.4
The use of BM should be encouraged among farm households	-	0.3	7.2	62.5	30.0
Mean ± SD	4.09 ± 0.42				

Table 5: The cost of swine production and production efficiency of small-scale swine farmers.

Catagories	Min	Max	Mean ± SD	Percentage
Hog price (USD)	166.79	250.00	197.96 ± 17.85	
Piglet price (USD)	22.80	64.59	38.01 ± 9.29	
Feed price (USD)	72.19	284.95	110.51 ± 19.09	
Veterinary price (USD)	1.90	341.95	30.77 ± 41.20	
Water-Electricity price (USD)	3.80	75.99	21.02 ± 14.81	
Production efficiency (%)				59
Production inefficiency (%)				41

In addition, 59% of the farmers demonstrated production efficiency, while 41% were found to be inefficient, suggesting that a considerable portion of smallholder swine farmers still face challenges in optimizing input use and reducing production costs (Figure 2).

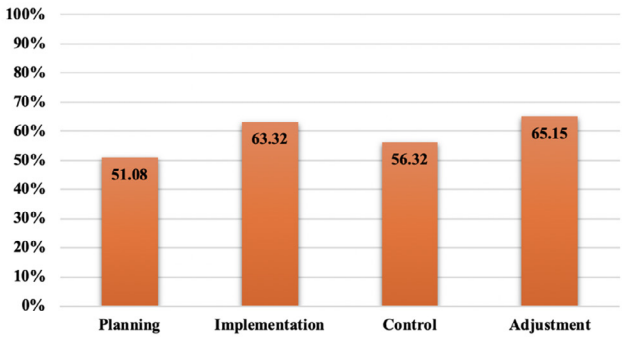

Figure 1: Biosecurity management practices in swine farms of the Mekong Delta.

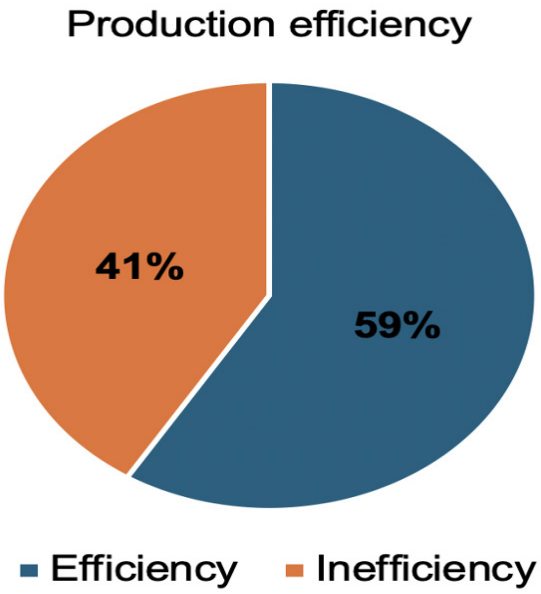

Figure 2: Production efficiency of small scale swine farmers.

The effect of socio-demographic characteristics and attitudes on biosecurity management

The results of Table 6 demonstrated that several socio-demographic characteristics and attitude factors influence applying biosecurity management, such as age, gender, main occupation, experience, family members, farm size and attitude toward biosecurity. An increase in main occupation, experience, family members, farm size and attitude increased by 1.826, 0.212, 0.514, 2.020 and 3.709 times, respectively, of the biosecurity management index, and all other factors were kept constant. Conversely, age and gender was found to have a negative association with BM adoption, indicating that younger and female farmers were more likely to apply biosecurity measures compared to their older counterparts. Education, labor and income did not significantly correlate with biosecurity management ($p > 0.05$). The equation could be written as follows: Y = -3.376 + (-0.149 x age) + (-2.108 x gender) + (1.826 x occupation) + (0.212 x experience) + (0.514 x family member) + (2.020 x farm size) + (3.709 x attitude).

The effect of biosecurity management on economic sustainability

The regression analysis (Table 7) revealed that biosecurity management (BM) had no statistically significant effect on economic sustainability ($B = -0.028$, $p > 0.05$). This indicates that variations in the level of BM implementation did not translate into measurable differences in the economic performance of swine farms. The equation could be written as follows: Y = 0.667 + (-0.028 x Biosecurity management).

DISCUSSION

The findings on socio-demographic characteristics align with previous research highlighting the influence of age and gender on biosecurity adoption (Qui *et al.*, 2020, 2024; Guntoro *et al.*, 2023). These results underscore the importance of carefully considering farmers' socio-demographic backgrounds when examining their decisions to implement biosecurity management practices (Guntoro *et al.*, 2023).

Similarly, Ritter *et al.* (2017) highlighted that each farmer has a unique combination of factors influencing their agricultural practices. The average age of farmers was consistent with the findings of Qui *et al.* (2024), indicating that most older farmers were actively engaged in swine farming activities. This may be explained by the fact that most of the younger generation tend to pursue education or employment opportunities in urban areas (Uddin *et al.* 2016). In addition, the finding are similar to the study of Kouam *et al.* (2018), in which most farm owners were male. Males tend to focus on agricultural activities than females, and swine production is dominant in their jobs. Besides, the level of education is slightly higher, with most farmers finishing undergraduate. It could influence the adoption of biosecurity management on their farm. Education and training enhance the ability of farmer and willingness to make successful changes to their management practice (Kilpatrick, 2000). In this study, the income and farm size of farmers was still at a medium level. According to Dung (2022), income plays an important role in adopting agricultural practices. Understanding these individual differences is crucial for developing effective agricultural interventions and supporting farmers in their decision-making processes.

Table 6: The effect of socio-demographic characteristics and psycological factors on biosecurity management.

Variables	Regression				
	B	Std. Error	Beta	t	Sig.
Age	-0.149**	0.033	-0.227	-4.470	0.000
Gender	-2.108**	0.558	-0.172	-3.777	0.000
Education	0.278	0.266	0.050	1.045	0.297
Occupation	1.826**	0.556	0.150	3.284	0.001
Experience	0.212**	0.037	0.299	5.803	0.000
Family member	0.514*	0.206	0.112	2.492	0.013
Labor	0.667	0.363	0.084	1.839	0.067
Farm size	2.020*	0.878	0.109	2.300	0.022
Income	0.000	0.001	-0.021	-0.400	0.689
Attitude	3.709**	0.599	0.304	6.192	0.000

Noted: sig.: significant; *significant at $p < 0.05$; **significant at $p < 0.01$. Adjusted R Square 0.296, F = 16.068, sig.000

Regarding biosecurity management, the findings indicate that farmers demonstrated strong proficiency in implementing and adjusting biosecurity measures, reflecting a practical and experience-based approach to disease prevention. As recorded in the study of (Cuc *et al.*, 2020; Scollo *et al.*, 2024; Anh *et al.*, 2023), biosecurity implementation is performed by most farms. The high proportion of farmers engaging in implementation and adjustment activities suggests that they are more accustomed to responding to immediate farm challenges rather than systematically planning or monitoring biosecurity programs. Similar observations were reported by Kouam *et al.* (2020), who noted that smallholder farmers tend to focus on visible, short-term practices rather than strategic or evaluative components of biosecurity management. The establishment of effective planning and control mechanisms can provide substantial benefits in the application of biosecurity practices. Previous studies showed that an effective biosecurity plan enhances preparedness by enabling farms to respond proactively to changing conditions (Anđelić *et al.*, 2017). Furthermore, control processes enable the identification of discrepancies between planned and actual practices, promote timely corrective actions, and enhance decision-making for improved biosecurity outcomes. According to Dědečková (2020), control plays a crucial role as an organizational function. Regular reassessment of biosecurity plans is essential to ensure their sustained effectiveness in disease prevention (Stanković *et al.*, 2016). Therefore, strengthening the planning and control aspects through training and advisory support could therefore enhance the overall effectiveness and sustainability of biosecurity practices in swine farms.

Table 7: The effect of biosecurity management on economic sustainability.

Variables	Regression				
	B	Std. Error	Wald	df	Sig.
Biosecurity management	-0.028	0.021	1.757	1	0.185

In term of attitude, the results indicate a consistently positive attitude toward BM among swine farmers, reflecting a strong behavioral and cognitive readiness for implementation. A substantial proportion of respondents expressed strong interest in applying BM, suggesting that biosecurity is widely recognized as a practical and beneficial strategy for herd health protection. Moreover, nearly 90% of respondents reported feeling adequately informed about BM, indicating effective communication and outreach efforts, consistent with reports that participatory training has significantly improved knowledge on the biosecurity practices (Alagesan *et al.*, 2025). Understanding of BM was also high, while yet the remaining a small of farmers who demonstrated only moderate comprehension emphasize the continuing need to improve extension materials and participatory learning approaches, as suggested by Hernández-Jover *et al.* (2021). Similarly, BM contributes positively to swine production performance is consistent with empirical evidence that better biosecurity may help to improve productivity and may contribute to reducing the use of antibiotics (Alarcón *et al.*, 2021). Community-level acceptance of BM further underscores the role of social norms and peer influence in sustaining collective biosecurity culture (Mankad et al., 2016). Finally, the near-unanimous support for encouraging BM among farm households demonstrates both social legitimacy and institutional trust, reinforcing that collective motivation and perceived social benefits are critical for sustained biosecurity adoption (Delabbio *et al.*, 2023).

The cost structure of small-scale swine farmers suggesting moderate market returns for smallholders. Feed costs accounted for the largest share of total expenses, reflecting their dominant role in overall production costs and their strong influence on farm profitability. Similar trends have been reported by Nguyen *et al.* (2021) and Kouam *et al.* (2020), who identified feed as the most significant determinant of economic efficiency in pig production systems. In contrast, expenses related to veterinary care, water, and electricity were relatively minor, indicating that farmers prioritize feed inputs over other cost components. The variability in input prices across farms may reflect differences in management practices, market access, and purchasing capacity. These findings highlight the importance of improving feed efficiency and cost management strategies to enhance profitability and sustainability among smallholder swine producers. In addition, 58.9% of the farmers demonstrated production

efficiency, while 41.1% were found to be inefficient, suggesting that a considerable portion of smallholder swine producers continue to face challenges in optimizing input use and minimizing production costs. This imbalance highlights existing gaps in management capacity, resource allocation, and technological adoption across farms. Similar findings were reported by Zelenyuk (2023), who emphasized that disparities in production efficiency among smallholders often arise from differences in access to quality feed, veterinary services, and farm management knowledge. The results imply that while more than half of the farmers are operating efficiently, targeted interventions-such as farmer training, improved input access, and biosecurity planning-are essential to enhance productivity and economic sustainability in the remaining group.

This study also noted that many socio-demographic characteristics influence biosecurity management such as age, gender, occupation, experience, family member and farm size. In terms of age, young farmers prefer participating in BM to the elder generation. This finding may be explained by the fact that the adoption of preventive measures requires flexibility and adaptability to changing disease dynamics and farm conditions that are often more pronounced among younger farmers. Similar to the findings of Brown *et al*. (2019), older farmers tend to be more risk-averse and less inclined to adopt new methods or technologies. In contrast, younger farmers are generally more open to innovation, enabling them to implement new measures that enhance production performance and livestock health. This aligns with the observations of Yang and Shih (2020), who reported that age significantly influences technology acceptance and the willingness to apply new production practices on farms.

Furthermore, farmers with larger families were more likely to engage in biosecurity management (BM) practices. Consistent with the findings of Can *et al*. (2020), a greater proportion of the population employed in agriculture positively influences biosecurity levels. As highlighted by Gao *et al*. (2017), farmers with larger families and more available labor are more likely to implement biosecurity measures effectively. This may be attributed to the increased manpower available for tasks such as vaccination, cleaning, and disinfection. Moreover, larger families can provide a more stable and reliable workforce, reducing dependence on external labor and, consequently, lowering the risk of disease introduction. Similarly, Qui *et al*. (2024) reported that farmers with additional support were better able to manage farming operations and prioritize disease prevention more efficiently. The finding that farmers whose primary occupation is animal husbandry exhibit stronger engagement in biosecurity management (BM) underscores the significant influence of livelihood dependency on biosecurity compliance. Farmers who depend mainly on livestock production tend to display greater awareness, motivation, and investment in preventive measures, as their income stability and farm sustainability are directly tied to herd health and productivity. This trend is consistent with previous studies, which reported that occupational specialization positively influences the adoption of biosecurity practices and enhances overall farm management efficiency (Nguyen et al., 2022; Le *et al*., 2021).

Regarding gender, female farmers tended to adopt preventive measures more actively than their male counterparts. However, previous studies have shown mixed findings. The results align with the findings of Backhans *et al*. (2015), who reported that farms owned by women tended to have higher biosecurity scores compared to those owned by men. This finding suggests that women continue to play a critical role in agricultural production, often taking primary responsibility for daily farm operations. Similarly, a study conducted in the Mekong Delta by Qui *et al*. (2020) indicated that men and women have equal access to swine production activities, though their level of participation may vary depending on farming conditions, social policies, and cultural factors. Moreover, biosecurity management tasks may be particularly well suited to women, who are often more attentive to activities requiring meticulousness and accuracy. Consistent with this, Rahutami and Matitaputty (2017) and Antriyandarti *et al*. (2024) highlighted that women contribute substantially to agricultural activities and assume major responsibilities in these processes. Moreover, women are often reported to invest more time and effort in farming than men. Satyavathi *et al*. (2010) also emphasized women's vital contribution to food production and rural livelihoods.

Additionally, the study found that some socio-demographic characteristics did not have a significant association with BM such as experience, education level and farm size. According to Kouam and Moussala (2018), farmers' age, gender, education level, and herd size did not significantly affect the level of biosecurity. Similarly, Lestari et al. (2021) found that household size showed no significant relationship with biosecurity practices among beef cattle farmers in Bone Regency. Hoang et al. (2024) also reported no significant correlations between demographic variables such as age, occupation, education, labor, family size, feeding practices, and farmers' knowledge or perceptions regarding the prevention of highly pathogenic avian influenza. However, these findings contrast with the study by Lestari et al. (2019), who found that education level had a significant influence on the adoption of biosecurity measures in beef cattle farms ($P < 0.01$). The

lack of significant associations in the present findings may be explained by the influence of other factors, such as farmers' personal backgrounds, previous experiences, access to information, and social environments, which can shape individual perceptions and behaviors (Hinjoy *et al*., 2023). Moreover, emotional states and normative beliefs have also been shown to exert a stronger influence on farmers' knowledge and preventive practices than socio-demographic characteristics (Doidge *et al*., 2021).

Additionally, farmers' attitudes toward biosecurity management (BM) were found to have a positive relationship. This underscores the critical influence of psychosocial factors in shaping behavior and decision-making at the farm level. Similarly, Tovmasyan (2017) emphasized that management activities are largely shaped by individual mental processes and are influenced by various elements such as managerial roles, expertise, leadership, decision-making and communication skills, as well as personality traits, temperament, and psychological characteristics.

The result indicated that BM measures did not influence economic sustainability, which suggests that the benefits of BM have not yet translated into measurable financial gains for smallholder pig producers in current production conditions. There are many factors can impact on applying prevention practices. Financial factors play a very important role in implementing biosecurity-related activities. According to Buckel *et al*. (2024), small-scale chicken farmers in Ghana face many financial difficulties despite their awareness of the importance of biosecurity. This can be pointed in study of Aliro *et al*. (2022), participants were hindered from preventing and controlling ASF due to biosecurity costs and a need to prioritise family livelihood over disease transmission risks, incompatibility of current biosecurity practises with local culture, traditions and social contexts and finally lack of access to veterinarians or, occasionally, low-quality veterinary services. Moreover, biosecurity measures are frequently applied in a fragmented or inconsistent manner rather than as part of an integrated farm management strategy, which limits their overall efficiency and economic impact. According to Mutua and Dione (2021) reveal a lack of adherence to biosecurity measures, even to the most basic biosecurity practices, especially for farmers and other actors in the pig value chain. Similarly, there were many challenges in adopting biosecurity such as cost constraints and varying compliance levels underscore the ongoing need for innovation and improved practices to safeguard the poultry industry and ensure sustainable production (Nontapan, 2024). Msimang *et al*. (2022) reported that specific farm attributes, especially farm size and degree of commercialization, were positively associated with the frequency of biosecurity practice adoption. Although biosecurity management (BM) is theoretically expected to reduce disease losses, enhance productivity, and lower treatment costs, its financial impact may be offset by the substantial initial investments and ongoing maintenance expenses required for implementation. Moreover, many smallholder farmers in developing regions, including Vietnam, tend to adopt biosecurity primarily as a preventive measure against disease outbreaks rather than as a strategy for profit maximization; consequently, the short-term economic gains remain modest (Truong *et al*., 2023). According to Fasina *et al*. (2012), full implementation of biosecurity measures can lead to a 9.70% reduction in total annual profit due to the associated costs. Similarly, Kees *et al*. (2023) reported that broiler farms must achieve further improvements in technical performance to compensate for the additional expenditures associated with enhanced biosecurity.

CONCLUSION

These findings highlight the importance of integrating social and behavioral dimensions into biosecurity improvement programs. Strengthening farmers' strategic planning and control capabilities through targeted training, extension services, and community-based interventions may enhance the overall effectiveness and sustainability of biosecurity practices in small-scale swine production systems. Furthermore, the results of this study indicate that although biosecurity management (BM) practices are widely recognized and partially implemented among smallholder swine producers, their measurable impact on short-term economic sustainability appears to be limited. This outcome does not imply that extension services should reduce or discontinue biosecurity promotion; rather, it highlights the need to reframe the narrative around BM. Instead of emphasizing immediate profit gains, extension programs should focus on BM as a risk mitigation and resilience-building strategy that protects animal health, reduces disease outbreak frequency, and ensures long-term farm viability. Overall, the study suggests that future biosecurity extension strategies should shift from a purely economic framing toward a preventive and adaptive management approach that enhances long-term sustainability under conditions of market and disease.

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NOVELTY STATEMENT

This study focus on manageging activities of biosecurity at smallholder farmer. Additionally, the research provides

novel insights into socioeconomic, behavioral, and structural factors to explain adoption decisions at the household level. Furthermore, it presents new evidence showing that the economic benefits of biosecurity are often limited for smallholders due to scale constraints, informal production systems, and low market incentives—an aspect largely overlooked in existing literature. By linking farmer perceptions, resource availability, and economic return analysis, this research highlights context-specific barriers and proposes more realistic, targeted pathways to improve biosecurity uptake in small-scale swine production.

AUTHOR'S CONTRIBUTION

NTAT, BG and ARSP designed the experiment. NTAT, CCD, NHQ and NTL collected and analyzed data. NTAT, NHQ, NL, NTL interpreted data and drafted the manuscript. NTAT, BG, ARSP and NHQ edited the manuscript. All authors carefully read and approved the manuscript for publication.

Generative AI and AI-assisted technology statement

This manuscript includes the assistance of AI tools for grammar refinement. All data analysis, interpretation, and conceptual insights were conducted by the authors.

Conflict of interest

The authors have declared no conflict of interest.

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