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Path analysis of farmer knowledge, attitudes, and practices toward lumpy skin disease in beef cattle

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Abstract

Lumpy skin disease (LSD) poses a significant threat to cattle populations and the livelihoods of farmers in Thailand. This study uses path analysis to explore the interrelationships among the knowledge, attitudes, and practices (KAP) of beef cattle farmers regarding LSD. A total of 384 farmers provided data on their sociodemographic characteristics and responses to KAP-related questions. Path analysis was employed to examine how KAP components interact and how demographic factors influence these relationships. The analysis revealed strong positive relationships between farmers' knowledge and attitudes ($\beta = 0.96$, $p < 0.001$) and between attitudes and practices ($\beta = 0.08$, $p < 0.008$). Farmers with greater knowledge of LSD were more likely to adopt positive attitudes toward disease control and implement effective management practices. Additionally, knowledge had a direct influence on farmers' practices ($\beta = 0.38$, $p < 0.001$), indicating that improved awareness of LSD is linked to better disease management. By strengthening knowledge, these efforts can positively influence attitudes and practices, leading to more effective control strategies. As the first KAP study on LSD in Thailand, this research highlights the critical role of targeted education programs in improving farmers' understanding of LSD. Ultimately, enhancing disease management through education can help reduce the economic impact of LSD on Thailand's livestock sector and promote sustainable farming practices.

Keywords Lumpy skin disease, KAP, Path analysis, Beef cattle, Farmers, Thailand

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Introduction

Lumpy skin disease (LSD) is one of the most severe poxvirus infections and is caused by Lumpy skin disease virus (LSDV), which belongs to the genus *Capripoxvirus* (Buller et al. 2005). This virus is closely related to sheep and goat pox viruses. It is also referred to as the Neethling virus within the subfamily *Chordopoxvirinae* of the family *Poxviridae* (Babiuk et al. 2008; Woods 1988). The primary host of LSDV is cattle, although other hosts, such as Asian water buffaloes, have been identified (Mazloum et al. 2023). The typical clinical signs of LSD include fever up to 41 °C, generalized lymphadenitis, and skin lumps that vary in size, mostly between 1 and 3 cm in diameter

and 1 to 2 cm in depth, with a firm consistency. Morbidity rates in cattle vary significantly, ranging from as low as 2% to over 85% (Elhaig, Selim, and Mahmoud 2017), while mortality rates are typically low, between 1 and 5%, although under certain conditions, they can reach upto 40% (Davies 1991). LSDV is transmitted primarily by insect vectors, which are responsible for their short-distance spread. However, the movement of cattle is considered the primary factor contributing to the long-distance dissemination of the virus (Tuppurainen and Oura 2012).

Since 2019, LSD outbreaks have been reported across Asia (WOAH 2023). The economic impact of LSD is substantial, with estimated losses of 1.45 billion USD across South, East, and Southeast Asia (Roche 2020). A study of 129 dairy farms in Thailand revealed that an LSD outbreak resulted in economic losses of 68,943 USD during the outbreak period (Vinitchaikul et al. 2023). Given the significant impact of LSD on cattle farming, understanding farmers' concerns, knowledge, attitudes, and behaviors is crucial for developing effective communication strategies and control measures (Balkhy et al. 2010). Effective disease control is closely linked to robust knowledge, attitudes, and practices (KAPs) regarding the disease (Alsaleh et al. 2023). In this context, assessing the KAP of farmers, who are key stakeholders in the cattle value chain, is vital for developing effective prevention and control strategies for LSD.

Various methods have been employed in the literature to analyze KAP, with one notable approach being path analysis-a technique within the structural equation modeling (SEM) family. Path analysis offers distinct advantages by using diagrams to bridge two seemingly disparate mathematical languages: visual models and statistical data (Pearl and Mackenzie 2018). This method enables the examination of more complex models, providing a deeper understanding of the relationships between variables. Path analysis has been used in various studies, such as the assessment of KAP concerning brucellosis surveillance (Kustiningsih et al. 2023) and an epidemiological study of echinococcosis (Burridge, Schwabe, and Pullum 1977).

Several studies on LSD have been conducted in Thailand; however, research on farmers' KAP regarding this disease remains limited, resulting in a critical knowledge gap. The objective of this study is to assess beef cattle farmers' KAP in relation to LSD and explore how knowledge influences practices, how attitudes shape implementation, and how knowledge impacts attitudes toward LSD through path analysis. The findings provide essential insights for targeted improvement measures and serve as important information for future training initiatives or policy-making efforts aimed at controlling disease outbreaks and mitigating economic losses.

Results

Sociodemographic characteristics of the farmers

The study included 384 beef farmers, as detailed in Table 1. The gender distribution revealed a greater proportion of males (60.9%) than females (39.1%). The age of the respondents ranged from 24–91 years, with the majority falling within the 43–60 age group, followed by those aged 61–78 years. The youngest (21–42 years) and oldest (79–96 years) age groups constituted smaller proportions of the sample. Educational attainment varied among participants, with primary education being the most common, followed by secondary education. A smaller proportion had less than primary education, whereas an even smaller fraction had completed tertiary education. The experience levels of the farmers were

Table 1 Beef farmers' demographic features and attributes ($n = 384$)

Variables	Absolute frequency (N)	Relative frequency (%)	95% Confidence Interval (CI)	
			Lower CI	Upper CI
Number of Participants				
Mueang	77	20.05	16.05	24.06
Na Klang	54	14.06	10.59	17.54
Na Wang	10	2.60	1.01	4.20
Suwannakhuha	58	15.10	11.52	18.69
Si Bunrueang	44	11.46	8.27	14.64
Non Sang	141	36.72	31.90	41.54
Gender				
Male	234	60.90	55.90	65.70
Female	150	39.10	34.30	44.10
Age				
24 – 42 years old	42	10.90	8.17	14.50
43 – 60 years old	221	57.60	52.50	62.40
61 – 78 years old	118	30.70	26.30	35.50
79 – 96 years old	3	0.78	0.25	2.41
Education				
Higher than High school	16	4.17	2.56	6.71
High school	100	26.00	21.90	30.70
Elementary	239	62.20	57.30	67.00
Under elementary	29	7.55	5.29	10.70
Experience				
1 – 15	303	78.90	74.50	82.70
16 – 30	70	18.20	14.70	22.40
31 – 45	4	1.04	0.39	2.75
46 – 61	7	1.82	0.87	3.79
LSD status				
Yes	210	54.70	49.70	59.60
No	174	45.30	40.40	50.30

diverse, with most reporting between 1 and 15 years of experience. A significant subset had 16–30 years of expertise, whereas those with 31–45 years and 46–61 years of experience represented a minor fraction of the sample. With respect to the presence of LSD on their farms, the respondents were almost evenly divided, with slightly more than half confirming the presence of LSD, whereas the remainder reported its absence.

Overall KAP of beef cattle farmers

Beef farmers demonstrated an average knowledge score of 0.62 ± 0.17 (mean ± standard deviation), an attitude score of 2.90 ± 0.42), and a mean practice score of 1.20 ± 0.27) for LSD management. A strong correlation was observed between knowledge and attitudes (correlation coefficient: $r = 0.52$).

Knowledge

Figure 1 illustrates varying levels of knowledge of LSD among beef cattle farmers, and the y-axis details are presented in Table 2. Most respondents understood the importance of prompt reporting and could recognize key clinical symptoms, notably characteristic lumps (1–5 cm) on the neck, head, and udder. They also supported the isolation of infected animals. Many correctly identified the primary vectors-ticks, mosquitoes, and stable flies-and endorsed the reduction of insect habitats as a preventive measure. Commonly recognized symptoms include fever and enlarged lymph nodes. A significant portion of farmers were also aware of treatment approaches on the basis of clinical signs. However, notable knowledge gaps exist. Only approximately half of the farmers recognized LSD's reproductive impacts, such as bull sterility and dam abortions, or the need for effective vector control. While most respondents knew that LSD rarely caused mortality, they acknowledged the disease's high morbidity risk. Knowledge of LSD's inclusion in the Thailand Animal Disease Act 2558 was limited, and few farmers believed LSD to be only a domestic concern. Interestingly, most participants erroneously considered LSD to be zoonotic. Nevertheless, they generally understood that LSD primarily affects cattle and buffalo and is not caused by bacteria.

Attitude

The attitudes of beef cattle farmers toward LSD control are illustrated in Fig. 2, with a detailed explanation of the y-axis items provided in Table 3. The majority acknowledged their crucial role in disease prevention and strongly supported collaboration with stakeholders. Farmers are aware of the impact of LSD on animal health and productivity and are committed to promptly reporting suspected cases. Most respondents recognized that healthy cattle were less susceptible to LSD and understood that the disease was highly contagious. However, opinions varied regarding control measures. While some farmers believed that LSD could not be controlled, others remained neutral. Most respondents felt that vaccination alone was sufficient, with no need for additional measures or postvaccination monitoring. There was disagreement about vaccinating cattle with fever symptoms, and some farmers contested the notion of immediate postvaccination immunity. The majority supported the use of netting for prevention and believed that light insect repellents were effective. Notably, many farmers found it acceptable to purchase new cattle during an outbreak.

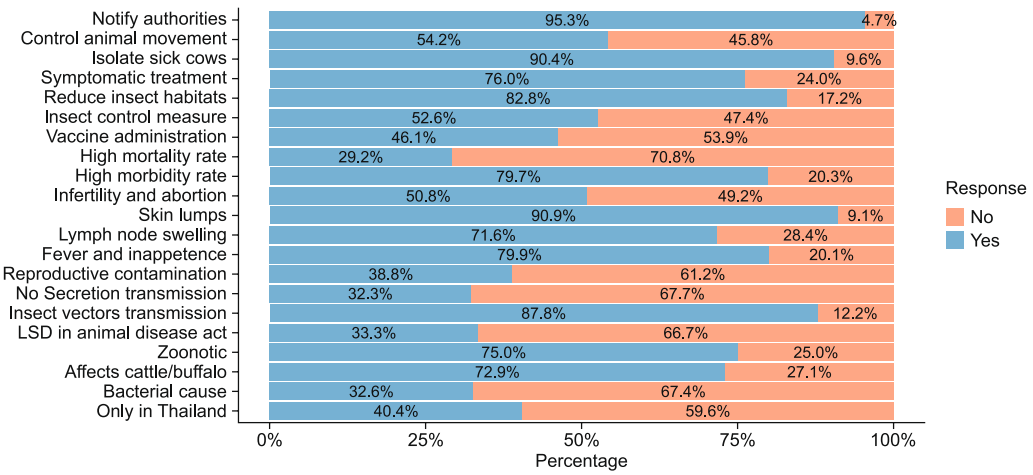

Figure1 Knowledge responses of beef cattle farmers on lumpy skin disease. Items on the y-axis are detailed in Table 2

Table 2 Knowledge items and descriptions of beef cattle farmers with respect to lumpy skin disease (LSD)

Item	Description
Only in Thailand	LSD is only found in Thailand
Bacterial cause	LSD is caused by bacteria
Affects cattle/buffalo	LSD primary affects cattle and buffalo
Zoonotic	LSD is a zoonosis
LSD in Animal Disease act	LSD is in the list of Thailand Animal Disease act 2558
Insect vectors transmission	Primary transmission is due to insect vector such as tick, mosquitoes and stable fly
No secretion transmission	LSD virus is not transmitted by secretion
Reproductive contamination	LSD virus can contaminate semen and placenta
Fever and inappetence	LSD clinical signs include fever 41° Celsius, inappetence
Lymph node swelling	Swelling of lymph nodes is a sign of LSD
Skin lumps	Clinical signs include lump with 1–5 cm in the body, mostly found in neck, head and udder areas
Infertility and abortion	LSD causes infertility in the bull. It can also cause abortion in dam
High morbidity rate	LSD has a high morbidity rate
High mortality rate	LSD has a high mortality rate
Vaccine administration	LSD vaccine can be used in both healthy cow and sick cow
Insect control measure	No need for insect control
Reduce insect habitats	Reduce habitat areas for insects can reduce risk of LSD
Symptomatic treatment	LSD is treated based on its clinical signs
Isolate sick cows	Separate LSD sick cow from the herd is necessary
Control animal movement	Animal movement control during the LSD outbreak is necessary
Notify authorities	Farmer should promptly notify the suspect LSD case to local livestock authority

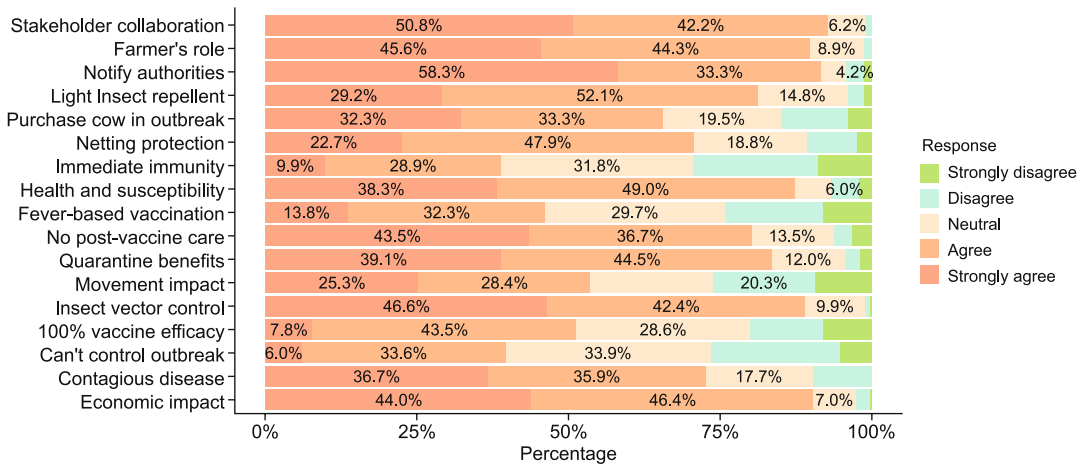

Fig. 2 Attitude responses of beef cattle farmers about lumpy skin disease. Items on the y-axis are detailed in Table 3

Practices

LSD management practices among beef cattle farmers are presented in Fig. 3, while Table 4 provides detailed descriptions of the y-axis items. Most beef cattle farmers were registered with local livestock authorities, although a few remained unregistered. During outbreaks, animal movement is a common practice for the vast majority of people. Biosecurity measures on farms varied, with few farmers keeping records of visitors or vehicles. Insecticide use was inconsistent; some farmers applied it regularly, whereas others used it occasionally. Most farmers actively monitor their cattle for signs of LSD, and more than half of the infected animals are isolated. Vaccination practices were less common, with fewer than one-third of the farmers implementing them. Those who did vaccinate generally monitored

Table 3 Attitude items and descriptions of beef cattle farmers toward lumpy skin disease (LSD)

Item	Description
Economic impact	LSD has impact on animal health and production
Contagious disease	LSD is a contagious disease
Can't control outbreak	It is not possible to control LSD outbreaks
100% vaccine efficacy	The vaccine provides 100% protection against LSD, so other control measures are not needed
Insect vector control	Reducing insect vectors can lower the risk of LSD
Movement impact	Animal movement control has no effect on LSD outbreak
Quarantine benefits	Separating an LSD-infected cow from the herd can reduce the spread of the disease
No postvaccine care	There is no need to monitor for adverse effects after vaccination with the LSD vaccine
Fever-based vaccination	If cattle show signs of fever, you can administer the LSD vaccine to them
Health and susceptibility	Cattle in good health are less susceptible to the disease
Immediate immunity	Cattle gain immunity immediately after vaccination
Netting protection	Using netting to protect cattle can reduce the risk of LSD
Purchase cow in outbreak	It is acceptable to purchase new cattle for the herd during an LSD outbreak
Light insect repellent	Using light insect repellent can help reduce the number of insects
Notify authorities	Farmers should promptly notify livestock authorities if a suspected case of LSD is observed
Farmer's role	Farmers play a key role in preventing the spread of LSD
Stakeholder collaboration	Collaboration among stakeholders is essential for controlling LSD

postvaccination outcomes and maintained their cattle's health. Vector control practices also vary widely. Frequent deworming is rare, but smoke repellents are commonly used. Herbal insect repellents were uncommon. Most farmers employ light-based repellent methods, and many use protective netting to guard against flies.

Factors associated with KAP

The factors associated with beef cattle farmers' KAP regarding LSD are summarized in Table 5. In the knowledge model, education, sex, experience, and age emerged as significant predictors. Surprisingly, education level (primary, secondary or tertiary), being female, and farming experience negatively impacted farmer knowledge. Age had a slight positive influence on knowledge, although this effect was not statistically significant. In the attitude model, age was the most influential factor, positively affecting attitudes. Education levels (primary, secondary, and tertiary), while statistically significant, had a negative effect on attitudes, which is consistent with their effect on knowledge. The practice model, however, revealed no statistically significant predictors since all the variables exceeded the threshold for inclusion.

Path analysis of the demographic factors and KAP of beef farmers

The regression path estimates for the KAP variables in relation to LSD, when considering significant demographic factors, are presented in Table 6. The standardized beta estimates are crucial since they reflect the direct impact of independent variables, such as the characteristics of beef farmers, on dependent variables (i.e., the KAP variables).

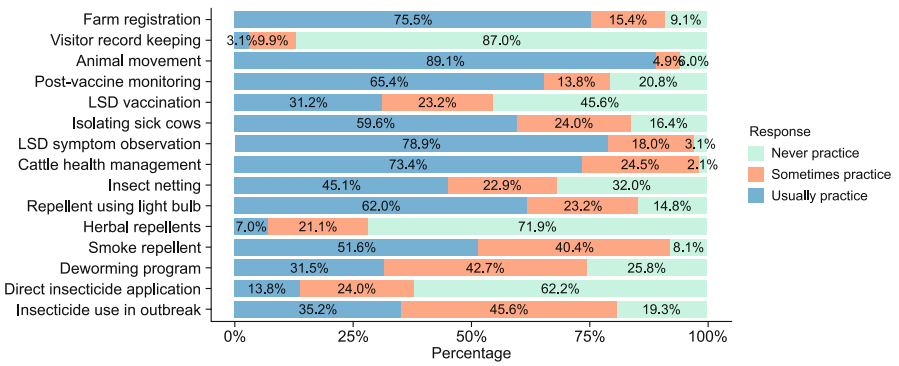

Fig. 3 Practice responses of beef cattle farmers to lumpy skin disease. The items on the y-axis are detailed in Table 4

Table 4 Practice items and descriptions of lumpy skin disease (LSD) among beef cattle farmers

Item	Description
Insecticide use in outbreak	Using insecticide in the farm area during an LSD outbreak
Direct Insecticide Application	Using insecticide applied directly to cattle
Deworming Program	Having deworming program
Smoke Repellent	Using smoke repellent to control insects in the farm
Herbal Repellents	Using herb as insect repellent
Repellent using light bulb	Using light bulb as insect repellent
Insect Netting	Using netting to control insects
Cattle Health Management	Managing to keep cattle in good health condition
LSD Symptom Observation	Observing cows for LSD clinical signs
Isolating Sick Cows	Separating sick cows from healthy cows
LSD Vaccination	Administering the LSD vaccine to cattle
Post-Vaccine Monitoring	Monitoring cattle after administering the LSD vaccine
Animal Movement	Moving animals during the outbreak
Visitor Record Keeping	The farm keeps records of visitors and their vehicles
Farm Registration	The farm is registered with the local livestock authority

The path diagram in Fig. 4 shows theoretically grounded causal relationships among variables, with directional arrows representing the hypothesized pathways of influence. Path coefficients, represented by standardized beta (β) estimates, quantify the magnitude and statistical significance of relationships between exogenous and endogenous variables. For example, demographic factors demonstrated statistically significant negative associations with knowledge: sex ($\beta = -0.93$, $p = 0.013$), secondary education level ($\beta = -2.14$, $p < 0.004$), and years of farming experience ($\beta = -0.04$, $p = 0.048$). Notably, an increase in education was associated with a decrease in LSD-specific knowledge. For the attitude variable, knowledge had a strong positive influence, with an estimate of 0.96 ($p < 0.001$). However, education was found to negatively affect the attitudes of beef cattle farmers. The results further demonstrated the significant positive effects of both knowledge and attitude on practices, with estimates of 0.38 ($p < 0.001$) and 0.08 ($p = 0.008$), respectively. These findings suggest that individuals with higher levels of knowledge and more positive attitudes are more likely to engage in the desired practices. The small arrows pointing to the dependent variables in the path diagram represent residual error, indicating unexplained variance

Table 5 Multiple linear regression results of beef farmers' characteristics and their knowledge, attitudes and practices

	Variable	Estimate	Standard Error	t value	Pr (>| t |)
Knowledge[a]	Intercept	14.35	1.31	10.97	< 0.001*
	Primary education	- 2.61	0.70	- 3.75	0.0002*
	Secondary education	- 2.02	0.75	- 2.71	0.0070*
	Tertiary education	- 3.17	1.15	- 2.76	0.0060
	Sex (female)	- 0.80	0.38	- 2.08	0.0378*
	Experience	–0.04	0.02	- 2.26	0.0240*
	Age	0.03	0.02	1.61	0.1089
Attitude[b]	Intercept	50.19	2.44	20.58	< 0.001*
	Primary education	- 6.05	1.36	- 4.42	1.3e^{-05}*
	Secondary education	- 5.17	1.46	- 3.54	0.0004*
	Tertiary education	- 4.62	2.20	- 2.10	0.0360*
	Age	0.08	0.04	2.05	0.040*
Practice[c]	Intercept	17.98	0.21	85.62	< 0.001*

[a] Akaike information criterion (AIC) value = 1359.24; R-squared (R^2) = 0.06

[b] Akaike information criterion (AIC) value = 1873.98; R-squared (R^2) = 0.06

[c] Akaike information criterion (AIC) value = 1473.53; R-squared (R^2) = 0.01

* Indicates a significant variable (p value < 0.05)

Table 6 Regression parameter estimates from path analysis

Dependent Variable	Independent Variable	Estimate (β)	Std. Error	z value	*p*- value
Knowledge	Sex (female)	−0.93	0.37	−2.49	0.013
	Primary education	−2.48	0.69	−3.60	0.000
	Secondary education	−2.14	0.74	−2.89	0.004
	Tertiary education	−3.58	1.11	−3.23	0.001
	Experience	−0.04	0.02	−1.98	0.048
Attitude	Age	0.05	0.03	1.46	0.145
	Primary education	−3.59	1.20	−2.99	0.003
	Secondary education	−3.37	1.27	−2.65	0.008
	Tertiary education	−2.21	1.91	−1.16	0.248
	Knowledge	0.96	0.09	11.18	< 0.001
Practice	Attitude	0.08	0.03	2.65	0.008
	Knowledge	0.38	0.06	6.17	< 0.001

in the KAP variables. The residual error for attitude was estimated at 35.48, suggesting substantial unexplained variance in this variable.

The final model exhibited a good fit, with a χ^2 value of 10.73 ($p = 0.29$). This fit was further supported by additional fit indices: CFI = 0.99, TLI = 0.98, RMSEA = 0.02, and SRMR = 0.02. Notably, the terms "Prim edu," "Sec edu," and "Tert edu" refer to primary, secondary, and tertiary education levels.

Discussion

This study assessed the KAP of beef cattle farmers in areas affected by LSD outbreaks. Notably, this is the first study in Thailand to utilize path analysis to explore the relationships among KAP components in the context of LSD.

The findings reveal that most farmers possessed a high level of knowledge regarding LSD. The respondents generally understood key aspects, including recognition of clinical signs, awareness of morbidity and mortality rates, the importance of isolating infected cattle, and the role of vaccination in disease control. These results are consistent with those of previous studies, which also revealed high levels of knowledge among participants in other regions affected by vector-borne diseases, suggesting that farmers tend to be well informed about diseases that pose a significant threat to livestock productivity (Alsaleh et al. 2023). This high level of knowledge may be attributed to the carefully designed questionnaire used in this study, which effectively assessed core knowledge of LSD, even if it did not explore the more nuanced aspects of the disease.

While minor variations existed in the attitudes of the farmers, overall, their responses were overwhelmingly positive. Many participants, particularly older farmers and those with more experience, recognized the economic impact of LSD and the importance of control measures, such as vaccination and vector control. This strong support for disease control aligns with previous studies examining attitudes toward vector-borne diseases in livestock farming (Alobuia et al. 2015). Age was not statistically significant but had a minor effect on attitudes. Younger dairy farmers and female farmers were more likely to adopt new management practices. In contrast, older and male farmers were less open to change, which is consistent with previous research (Nyanga 2012). Overall, the majority of farmers reported regularly observing cows for clinical signs, monitoring cattle postvaccination, implementing vector control measures, and registering their farms with local authorities, demonstrating good practices. These practices are essential for the prevention and control of LSD, highlighting the need to maintain consistent management strategies to reduce the impact of this disease on livestock.

The Pearson's correlation matrix in Table 7 indicates strong positive associations among the KAP scores of beef cattle farmers, demonstrating that higher knowledge scores are linked to more favorable attitudes and improved practices regarding LSD. Farmers with greater knowledge of LSD had more informed attitudes and were more likely to adopt appropriate practices to manage the disease. Furthermore, path analysis, a valuable tool for disentangling complex interrelationships among variables (Stage, Carter, and Nora 2004), provided further insight into the dynamics of KAP in this study. The present study demonstrates key relationships among variables that shape beef cattle farmers' KAP in the context of LSD control. The path analysis in this study examined different paths between selected

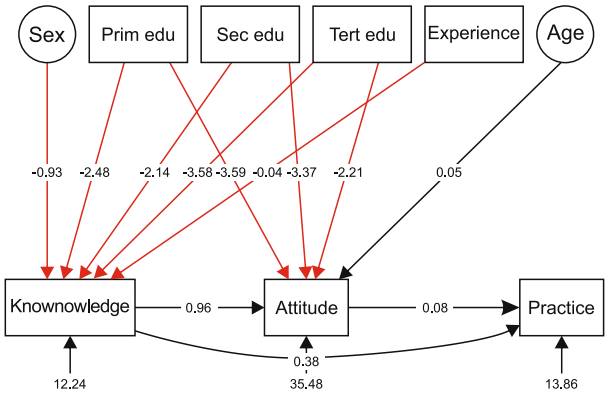

Fig. 4 Path analysis model illustrating the relationships between selected demographic factors and Knowledge, Attitudes, and Practices (KAP). The numbers on the arrows represent standardized path coefficients, indicating the relative strength of the relationships. For instance, primary education demonstrates the strongest negative influence on farmers' attitudes, while knowledge exerts the most significant positive effect on attitudes toward lumpy skin disease. Red arrows denote negative path coefficients, black arrows indicate positive path coefficients, and small black arrows represent residual errors

Table 7 Pearson's correlation coefficients among the knowledge, attitudes and practices of beef cattle farmers

Variable	Knowledge	Attitude	Practice
Knowledge	1.00*		
Attitude	0.52*	1.00*	
Practice	0.41*	0.31*	1.00*

* Indicates a level of statistical significance ($P < 0.001$)

demographic factors and KAP, as well as among the KAP components of beef cattle farmers, as presented in Fig. 4. One of the key significant findings is the negative effect of being female on beef cattle farmers' knowledge regarding LSD. This result likely reflects gender-based disparities in access to agricultural education and extension services, where male farmers typically benefit from more opportunities for training and information dissemination (Habiyaremye et al. 2017). Addressing these disparities is essential for improving women's access to knowledge of animal health and disease control, particularly in rural settings.

This study revealed significant paths according to education level, with primary, secondary, and tertiary education all negatively influencing the knowledge and attitudes of beef cattle farmers. Tertiary education had the most substantial negative impact on knowledge ($\beta = -3.58$, $p < 0.001$), followed by primary ($\beta = -2.48$, $p = 0.001$) and secondary education ($\beta = -2.14$, $p = 0.004$). These negative path estimates suggest that higher education levels may not necessarily translate into better knowledge and attitudes toward LSD, potentially because of factors such as urban–rural disparities, reliance on traditional livestock farming practices, and limited access to education. For example, they rely on traditional practices, where farmers prioritize experiential knowledge over education regardless of their education level. It is possible that individuals with tertiary education are less engaged in hands-on livestock management, which could limit their practical knowledge of disease prevention and management. Furthermore, the introduction of LSD in Asian countries is relatively recent, and existing educational curricula may not adequately address LSD as an emerging livestock disease. This situation is exacerbated by the generally low educational attainment of beef cattle farmers in the sample under study, with a majority (62.2%) having attended only primary school. This finding aligns with previous KAP studies on livestock producers regarding antimicrobial use in Ethiopia (Tufa et al. 2023) and KAP among patients with anemia toward disease management in China (Yao et al. 2024), with negative relationships also being reported between education and knowledge and attitudes. Farmers' perceptions of LSD are shaped by cultural and religious beliefs, i.e., visiting shrines or using holy verses for treatment. This is because most beef cattle farmers have only a primary education, highlighting the need for a culturally sensitive and accessible educational intervention program, which aligns with a previous KAP study related to brucellosis in Pakistan (Arif et al. 2017). However, the present study provides new insights into the specific context of LSD management among beef cattle farmers in Thailand.

Farming experience was found to negatively influence knowledge, which aligns with the findings of a previous study in Thailand, which revealed that older farmers were more likely to have experienced LSD outbreaks because of their longer involvement in farming. However, younger farmers, while less likely to have direct experience with outbreaks, tend to engage more with various media sources, giving them greater access to up-to-date information and knowledge of LSD (Arjkumpa et al. 2024). This is particularly important since the use of internet websites and social media to share information has become a key strategy for increasing awareness and knowledge of LSD in Thailand (Arjkumpa et al. 2022; Suwankitwat et al. 2022; Arjkumpa et al. 2024). These findings highlight the importance of tailored educational programs to increase farmers' knowledge of LSD. While older farmers may rely on traditional experience, younger farmers, who tend to engage more with modern media, have greater access to

updated information. This underscores the need for communication strategies that leverage digital platforms such as social media and websites to improve awareness and understanding of LSD among farmers. Furthermore, the results indicate that age has no significant effect on attitudes, suggesting that age alone does not shape farmers' perspectives on LSD control. However, age may interact with experience and openness to new knowledge, indirectly influencing attitudes and practices.

Path analysis also highlighted the significant direct effects of knowledge on attitudes and the positive effects of both knowledge and attitudes on practices. These results suggest that farmers with greater knowledge of disease and farming exhibit more positive attitudes and are more likely to engage in practices that help them address disease outbreaks. This aligns with prior research showing that farmers with more positive attitudes toward disease management are more likely to implement appropriate control measures (Zeweld et al. 2017). The findings of the present study are consistent with those of previous research on dairy farmers in Indonesia in that improving farmers' knowledge and understanding of brucellosis surveillance and control can lead to more positive attitudes and better health management practices (Kustiningsih et al. 2023). For example, farmers who participate in training programs may be more likely to adopt best practices for disease prevention and control. This underscores the importance of comprehensive education and training programs for improving overall farm management and disease control strategies. By addressing the knowledge gaps and attitudes of farmers, such programs can contribute to better disease management outcomes and improved livestock productivity.

This study has several limitations. First, the questionnaire-based design may introduce potential biases since respondents might answer on the basis of their perceptions rather than actual knowledge or practices, which could lead to discrepancies in the findings. To mitigate this, the importance of providing accurate answers was emphasized to the respondents as being essential for improving LSD prevention and control efforts. Second, the questionnaire was developed by experts in Thailand to ensure that the questions were specifically designed to address the local context, including topics related to farm management and disease prevention strategies. However, some findings may not be fully generalizable to other regions, where differences in farmers' characteristics, farm management practices, and methods of acquiring knowledge, such as media usage behaviors, may vary. Finally, this study does not aim to explore latent variables or capture more complex relationships, which would require advanced statistical methods such as structural equation modeling.

Future investigations might focus on the effects of specific education programs on improving KAP and explore the causes of sex- and experience-based gaps in LSD knowledge and attitudes. Additionally, long-term studies could monitor other demographic factors, track KAP changes over time, and assess the efficacy of different disease control strategies.

Conclusions

This study used path analysis to examine the relationships between farmers' KAP and LSD management. The analysis revealed strong, positive connections between knowledge and attitudes, as well as between attitudes and practices, indicating that improving knowledge leads to better disease management practices. This suggests that targeted interventions focused on enhancing farmers' understanding of LSD can directly influence their actions, leading to more effective control and prevention strategies.

Methods

Study area and sampling

A cross-sectional study utilizing a questionnaire survey was conducted from July to October 2022 on beef cattle farms across all six districts of Nong Bua Lamphu Province in northeastern Thailand (Fig. 5). This province borders Udon Thani to the east, Khon Kaen to the south, and Loei to the north. Recent demographic data indicate that Nong Bua Lamphu has a population of 508,325, with an almost equal gender distribution of 253,342 males and 254,983 females (National Statistical Office, 2023). The province is predominantly rural in both its landscape and population (Tourism Authority of Thailand, 2003). In 2022, the provincial livestock office database recorded a total of 54,856 beef cattle in the province. Given that LSD outbreaks were reported in all six districts of the province during 2021, including Mueang, Na Klang, Na Wang, Suwannakhuha, Si Bunrueang, and Non Sang (Fig. 5), questionnaire surveys were distributed across these districts to ensure a representative overview.

A simple random sampling method was used for the field survey. The sample size was calculated via Taro Yamane's formula (Yamane 1973) to calculate sample sizes with an acceptable margin of error;

$$n = \frac{\mathrm{N}}{1 + Ne^2}$$

where n = sample size, N = population size and e = error, set as 0.05.

With a total population of 5,007 beef cattle farmers, the minimum required sample size was determined to be 370. However, to ensure robustness, precision, and

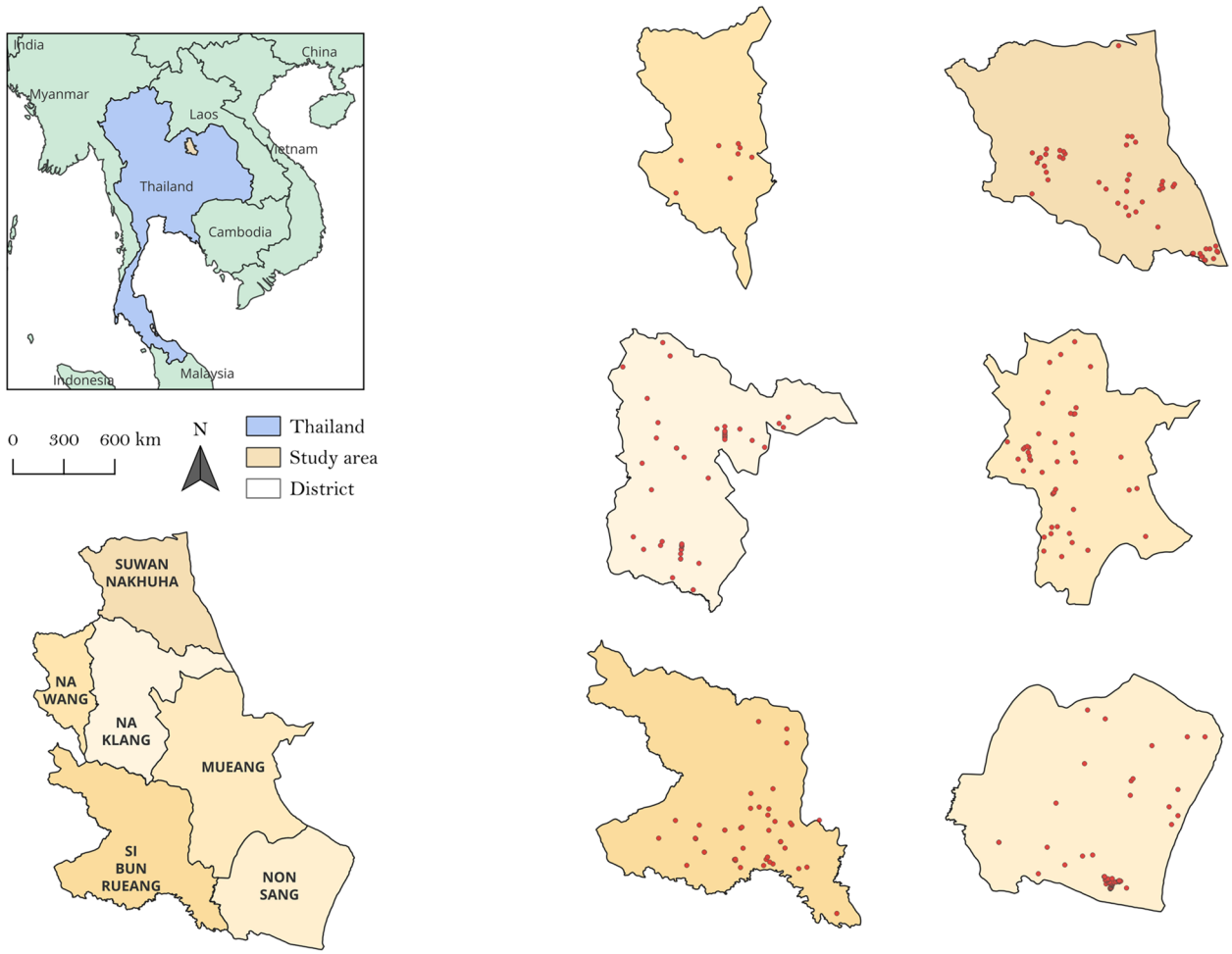

Fig. 5 A map of the study area, comprising six districts in Nong Bua Lamphu Province in Northeastern Thailand. The red dots indicate the geographical locations (latitude and longitude) of beef cattle farms within each district of the province

confidence in the results, a slightly larger sample size of 384 participants was used. Given that the study covered all six districts, the total sample size (n = 384) was distributed proportionally to the total population of beef cattle farmers in each district, ensuring that the representation accounted for the varying population sizes across districts.

The number of beef cattle farmers in each district was calculated proportionally on the basis of the total number of beef cattle farmers in the district. A list of registered beef cattle farmers in Nong Bua Lamphu was retrieved from the Nong Bua Lamphu provincial livestock database. In each district, beef cattle farmers were randomly selected from this list. With the cooperation of district livestock authorities, farm owners were contacted via phone. Only farmers willing to participate were included in the study. This process was repeated until the required sample size was achieved.

Survey design and questionnaire

The questionnaire used in this study was expertly designed by veterinary professionals from the Department of Livestock Development (DLD), Ministry of Agriculture and Cooperatives. These professionals exhibited extensive experience in livestock disease outbreak investigations and possessed a strong background in veterinary epidemiology. The questionnaire has been validated and used in several LSD outbreaks by DLD officers. A preliminary test was conducted with 60 beef cattle farm owners who were evenly distributed across all six districts (10 farmers per district) to evaluate the clarity and accuracy of the questionnaire. This assessment focused on identifying issues related to the interpretation of questions, the recall of vital information, judgment, and answer editing. Cronbach's alpha coefficient was calculated to determine the reliability of the questionnaire, yielding a value of 0.78. Since this value exceeded the threshold of 0.70,

it was deemed sufficient for consistent internal reliability. Insights from the response process validity assessment were used to refine and finalize the questionnaire, making it suitable for self-administration.

The questionnaire consisted of four sections. The first section collected personal data from the beef farmers, including their name, age, gender, education level, experience, and exposure to LSD outbreaks. The second section assessed their knowledge and understanding of LSD prevention and control. The third section examined the farmers' attitudes toward LSD. The final section evaluated their practices in relation to LSD.

For the knowledge assessment, participants could respond with "yes," "no," or "don't know." To assess attitudes, participants were asked to indicate their level of agreement (from strongly disagree to strongly agree) with various statements via a five-point Likert scale (Joshi et al. 2015). For the practice assessment, a three-point Likert scale (Never = 0, Sometimes = 1, Usually, = 2) was employed.

Data collection

A total of 384 participants were enrolled in this study on the basis of the following criteria: participants had to be 18 years or older, actively raising beef cattle (defined as participants both owner and nonowner beef cattle farm managers directly involved in daily cattle management, including feeding, breeding, and health care), possess a minimum of one year of farming experience and reside in Nong Bua Lamphu Province.

Data were collected through face–to-face interviews from July to September 2022 via a combination of closed-ended and open-ended questions. However, for the purposes of quantitative analysis, only the responses to the closed-ended questions were used, whereas the open-ended comments served as supplementary notes to provide additional context and understanding of the respondents' answers. The questionnaire included sociodemographic information categorized into different groups. For example, experience was divided into four groups, with the 1–15 years of experience group based on Anders Ericsson's theory of deliberate practice (Ericsson et al. 1993) and supported by a previous study (Ojoko et al. 2017). The questionnaire also contained 21 knowledge-based questions, 17 attitude-based questions, and 15 practice-based items to assess the understanding, attitudes, and practices related to LSD among beef cattle farmers.

Data analysis

Data analysis was conducted via RStudio V. 4.4.1. In the assessment of knowledge-based questions, respondents were awarded 1 point for correct answers and 0 points for incorrect answers. Attitude-related questions were evaluated via a Likert scale with response options coded as follows: "strongly agree" (4), "agree" (3), "neutral" (2), "disagree" (1), and "strongly disagree" (0). For questions pertaining to practice behaviors, the responses were categorized and coded as "usually practice" (2), "sometimes practice" (1), or "never practice" (0). The statistical significance for all tests was set at the 0.05 level. The data analysis for this study consisted of three steps: descriptive statistics, stepwise multiple linear regression, and path analysis.

Descriptive statistics were utilized to determine the relative and absolute frequencies, mean standard deviation (SD), and median of KAP. Furthermore, correlations among K, A and P were determined *via* Pearson's correlation test, which utilized the total mean score of each variable to examine the relationships among them. Moreover, stepwise multiple linear regression was used, combining forward selection to determine the factors associated with each K, A, and P (Smith 2018). R packages, including "psych," "gmodels," "ggplot2," and "StepReg" (Revelle 2024; Rogers 2024; Wickham 2016; Zhu 2024), were used for the analysis. Moreover, multicollinearity, according to a high degree of correlation between independent variables, was examined. It was assessed via the variation inflation factor (VIF). A VIF value of less than five indicated that multicollinearity was not serious, whereas a VIF value greater than five suggested substantial multicollinearity. When the VIF exceeded 10, multicollinearity was considered severe (Ghani and Ahmad 2010). Furthermore, R square (R^2) and Akaike's information criterion were determined from the final model (Lindsey and Sheather 2010).

Path analysis was conducted *via* the "lavaan" package in RStudio (Rosseel, 2012) to examine the direct effects of beef farmers' knowledge on their attitudes, as well as the direct effects of both knowledge and attitudes on their LSD practices. The path diagram, which integrated qualitative "arrow information" with quantitative "data information," was visualized via the "semPlot" package in RStudio (Epskamp 2022). This method offered a comprehensive view of the parameter estimates for both independent and dependent variables, akin to combining two foreign languages (Pearl and Mackenzie 2018). Model fit was evaluated via the chi-square (χ^2) test despite its sensitivity to the number of variables included in the model and the available sample size (Keith 2019). To mitigate these limitations, additional fit indices were employed. The comparative fit index (CFI) uses a cutoff criterion of CFI $\geq$ 0.90, although recent studies suggest that a value exceeding 0.90 is essential to avoid accepting misspecified models (Hu and Bentler 1999). The Tucker Lewis Index (TLI), also known as the nonnormed fit index (NNFI),

considers values between 0.90 and 0.95 as marginal, over 0.95 as indicative of a good fit, and below 0.90 as reflecting poor fit (Kenny, 2024). For the root mean square error of approximation (RMSEA), values between 0.08 and 0.10 indicate a mediocre fit, whereas values below 0.08 are considered good (MacCallum, Browne, and Sugawara 1996). Finally, the standardized root mean squared residual (SRMR) uses a recommended cutoff value close to 0.08 to assess model fit (Hu and Bentler 1999).

Abbreviations

KAP	Knowledge, Attitude and Practice
LSD	Lumpy Skin Disease
LSDV	Lressy Skin Disease Virus
FMD	Foot and Mouth Disease
SEM	Structural equation modeling
DLD	Department of Livestock Development
SD	Standard deviation
VIF	Variant Inflation Factor
χ^2	Chi-square test
CFI	Comparative Fit Index
TLI	Tucker Lewis Index
NNFI	Nonnormed fit index
RMSEA	Root mean square error of approximation
SRMR	Standardized root mean square residual

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Authors' contributions
Conceptual and design of the study: all authors. Investigation and data collection: DA, JP, MS and OA. Data curation and validation: DA, JP, MS, OA, WC, KN, SS and VP. Data visualization: SK, SS and VP. Formal analysis: SK, SS and VP. Writing-original draft preparation: SK and VP. Writing-review and editing: All authors. Supervision: OA, WC, KN and VP. Funding acquisition: VP. All the authors have read and agreed to the published version of the manuscript.

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Data availability
The data used in this study are available upon reasonable request to the corresponding author.

Declarations

Ethics approval and consent to participate
This study received ethical approval from the Mahidol University Central Institutional Review Board (COE No. MU-CIRB 2022/018.0402) and was conducted in accordance with applicable guidelines and regulations.

Consent for publication
All authors of this article have agreed to publish this article in Animal Diseases.

Competing interests
The authors declare that they have no conflicts of interest.

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