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RESEARCH ARTICLE

Knowledge–practice gaps and direct and indirect associations among knowledge, attitudes, and preventive practices regarding brucellosis and coxiellosis among meat goat farmers in northeastern Thailand

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ABSTRACT

Background and Aim: Brucellosis and coxiellosis are important reproductive zoonoses affecting small ruminants and posing occupational risks to livestock farmers. Although both infections are present in northeastern Thailand, farmers' knowledge, attitudes, and preventive practices (KAP) remain poorly characterized. This study assessed KAP regarding brucellosis and coxiellosis among meat goat farmers, identified associated demographic and herd-related factors, and examined direct and indirect associations among KAP domains.

Materials and Methods: A cross-sectional survey was conducted from April 2024 to March 2025 in Khon Kaen and Chaiyaphum Provinces, Thailand. Using convenience sampling, 146 meat goat farmers were recruited from a provincial farmers' network, compared with a target sample of 329. A structured questionnaire assessed knowledge (14 items), attitudes (15 items), and preventive practices (44 items). Internal consistency was evaluated using Cronbach's alpha. Multiple linear regression, correlation analysis, and path analysis were performed to identify associated factors and examine relationships among KAP domains.

Results: Mean knowledge, attitude, and practice scores were 66.54% (95% confidence interval [CI]: 63.43–69.64), 81.60% (95% CI: 79.57–83.63), and 51.07% (95% CI: 48.79–53.36), respectively, demonstrating a substantial knowledge–practice gap despite favorable attitudes. Awareness of coxiellosis was particularly limited (2.74%) compared with brucellosis (43.15%). Knowledge was weakly correlated with preventive practices (Spearman's $\rho = 0.28$, $p < 0.001$). Path analysis identified significant direct associations of knowledge ($b = 0.37$, 95% CI: 0.03–0.72, $p = 0.033$) and attitudes ($b = 0.54$, 95% CI: 0.29–0.80, $p < 0.001$) with preventive practices, alongside an indirect association through attitudes. Higher knowledge was associated with graduate education, whereas improved practices were associated with reported herd arthritis. The model explained 27.50% of the variance in preventive practices.

Conclusion: Substantial gaps between disease awareness, favorable attitudes, and preventive practices highlight the need for targeted, literacy-sensitive farmer education integrated with affordable diagnostic testing and veterinary support. Because recruitment was nonrandom and below the target sample size, these associations require confirmation in larger, representative studies.

Keywords: brucellosis, coxiellosis, goat farming, knowledge–attitude–practice, One Health, path analysis, preventive practices, zoonotic diseases.

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INTRODUCTION

Over the past decade, meat goat production has become one of Thailand's fastest-growing livestock sectors. The national goat population increased from 832,533 in 2019 to 1,568,059 in 2023, representing an 88.35% increase. Growth was particularly pronounced in northeastern Thailand, where the goat population increased from 96,489 to 338,779 (251.11%), accompanied by a 290.51% increase in registered goat farmers [1–5]. Although rising market demand and supportive agricultural policies have driven this expansion, growing goat production may also increase opportunities for zoonotic disease transmission, particularly brucellosis and coxiellosis [6, 7]. Both diseases can adversely affect herd productivity through reproductive disorders and pose occupational health risks to farmers, their families, and veterinary personnel, especially through exposure to infected animals and reproductive materials during parturition [8–10].

Recent epidemiological investigations have confirmed the circulation of *Brucella* spp. and *Coxiella burnetii* in meat goat herds in northeastern Thailand. Real-time polymerase chain reaction (PCR) detected *Brucella* spp. DNA in 11 samples from eight herds, with intraherd prevalence ranging from 4.74% to 8.72% [11]. Similarly, *C. burnetii* was detected by serological and/or real-time PCR testing in 29 of 39 herds, corresponding to a combined serological and molecular herd-level prevalence of 74.35% [12]. Movement of breeding bucks between herds is an important on-farm risk factor for reproductive pathogens, whereas routine annual brucellosis testing is associated with reduced reproductive failure risk [13]. Brucellosis and coxiellosis may produce overlapping reproductive manifestations in goats, including abortion, stillbirth, and weak-born offspring. Other clinical manifestations, including orchitis and arthritis, may also occur [13]. Because these clinical signs are not sufficiently specific to reliably distinguish the infections, laboratory confirmation is important for accurate diagnosis and appropriate disease management. However, small-scale goat farmers may have limited access to diagnostic services, which can delay disease recognition and implementation of preventive measures.

Farmers' knowledge, attitudes, and practices (KAP) are important considerations in preventing and controlling livestock-associated zoonotic diseases. KAP assessments can identify deficiencies in disease awareness, misconceptions about transmission, perceptions of disease severity, and preventive behaviors that may influence on-farm biosecurity. Such assessments can also provide baseline information for developing educational interventions and evaluating subsequent changes in disease-related knowledge and practices [14]. Nevertheless, conventional KAP surveys have limitations because standardized biomedical questionnaires may not adequately capture locally established knowledge, cultural practices, or contextual barriers to disease prevention. Furthermore, improved knowledge does not necessarily result in the adoption of appropriate preventive behaviors.

Evidence from other livestock production systems illustrates potential discrepancies across KAP domains. A study involving sheep and goat farmers in China reported satisfactory attitude and practice scores despite inadequate knowledge, particularly concerning disease transmission routes. The study also identified key gaps in preventive behavior, including inconsistent handwashing after animal contact [15]. These findings indicate that favorable attitudes or adequate general knowledge may not be sufficient to ensure consistent implementation of biosecurity measures. Consequently, evaluating the relationships among KAP is essential for understanding the factors associated with farmers' preventive behaviors.

Brucellosis and coxiellosis share several important transmission-related characteristics, making their combined assessment relevant to goat production systems. Both infections require attention to hygienic management during parturition, safe handling and disposal of reproductive materials, and appropriate use of personal protective equipment when assisting with kidding. However, certain prevention and control measures differ between the diseases. In Thailand, the Department of Livestock Development requires annual brucellosis testing of goats and sheep aged 4 months or older [16] and provides a voluntary brucellosis-free farm certification scheme, under which animals introduced into certified farms must originate from farms of equal or higher certified status or test negative within the preceding 3 months [17]. No equivalent testing or certification requirements have been specified for coxiellosis [16, 17]. In contrast, because *C. burnetii* is transmitted primarily through aerosols and can infect a wide range of animals, prevention of *C. burnetii* exposure also requires particular attention to potential environmental and animal-associated sources of infection, including ticks [7]. Evaluating both diseases within the same farming population may therefore identify shared deficiencies in routine biosecurity alongside disease-specific gaps in awareness and preventive practices.

Beyond descriptive assessment, understanding how KAP domains are associated may provide useful information for designing targeted interventions. Conventional KAP models generally propose that knowledge

influences attitudes, which may subsequently influence preventive practices. However, these relationships may vary across populations because education, prior disease experience, available resources, herd management characteristics, and access to veterinary services also shape behavioral decisions. Path analysis provides a statistical framework for examining multiple associations simultaneously and distinguishing direct associations from indirect associations operating through intermediate variables [18]. In cross-sectional research, however, these pathways represent hypothesized statistical relationships rather than evidence of causality or temporal sequence.

Despite the substantial expansion of meat goat production and documented circulation of *Brucella* spp. and *C. burnetii* in northeastern Thailand, evidence concerning farmers' awareness and preventive behaviors remains insufficient. Previous research has assessed brucellosis-related KAP among small-scale goat farmers in central Thailand [19], while epidemiological investigations have demonstrated the presence of both pathogens in northeastern meat goat herds [11, 12]. However, these findings do not establish whether farmers in northeastern Thailand recognize the two diseases, understand their transmission pathways, perceive their occupational and animal health risks, or consistently implement appropriate preventive measures. In particular, awareness of coxiellosis and the extent to which farmers distinguish its prevention requirements from those of brucellosis remain poorly characterized.

A further knowledge gap concerns the relationships among KAP domains within this rapidly expanding production system. Although farmers may express favorable attitudes toward disease prevention, it is unclear how these attitudes translate into actual preventive practices. Similarly, the influence of educational attainment, farming experience, herd characteristics, and previous reproductive health problems on KAP has not been adequately established in this population. Previous descriptive KAP investigations have provided valuable information on individual domains, but evidence on their simultaneous direct and indirect associations remains limited. Specifically, it remains uncertain whether knowledge is associated with preventive practices independently of attitudes or whether part of this association operates indirectly through attitudes.

Addressing these gaps is important for developing locally relevant, evidence-based, and culturally appropriate disease prevention strategies. Identifying discrepancies between disease awareness and preventive behavior may help prioritize farmer education, veterinary extension services, diagnostic accessibility, and practical biosecurity interventions. Such information is particularly relevant to rural communities where frequent human–livestock contact creates opportunities for zoonotic exposure and where disease prevention requires coordinated consideration of animal, human, and environmental health [20, 21]. The distinctive contribution of the present study is therefore the joint evaluation of brucellosis- and coxiellosis-related KAP among meat goat farmers in a region where both pathogens have been documented, combined with path analysis to examine the structure of associations among KAP domains and relevant farmer and herd characteristics.

This study aimed to assess KAP regarding brucellosis and coxiellosis among meat goat farmers in Khon Kaen and Chaiyaphum Provinces, northeastern Thailand, and to identify factors associated with the adoption of preventive measures. Specifically, the objectives were to (1) evaluate farmers' knowledge of both diseases, their attitudes toward disease prevention, and their reported implementation of preventive practices; (2) identify demographic and herd-related characteristics associated with each KAP domain; and (3) examine the direct and indirect associations among knowledge, attitudes, and preventive practices using path analysis, while accounting for relevant demographic and herd-related factors.

The study hypothesized that greater disease-related knowledge would be positively associated with both favorable attitudes and preventive practices and that part of the association between knowledge and preventive practices would operate indirectly through attitudes (a statistical indirect association rather than causal mediation), consistent with the conventional sequential KAP framework. Because the investigation used a cross-sectional design, the proposed pathways aimed to characterize associations rather than establish causal relationships. The findings were expected to inform targeted farmer education, strengthen veterinary extension activities, and support practical biosecurity interventions addressing brucellosis and coxiellosis in northeastern Thailand.

MATERIALS AND METHODS

Ethical approval

The study protocol was reviewed and approved by the Center for Ethics in Human Research, Khon Kaen University, Thailand (approval no. HE672063; April 2024). Informed consent was obtained from all participants

before questionnaire administration using the approved participant information sheet and consent form dated April 2, 2024. Consent procedures were adapted to the three approved questionnaire administration methods. Participants completing self-administered or interviewer-administered paper questionnaires provided written consent by signing the consent form. For participants unable to read, the information sheet and consent form were read aloud, and consent was documented by thumbprint in the presence of an independent witness, who countersigned the form. Participants completing the online questionnaire provided electronic consent through Google Forms (Google LLC, Mountain View, CA, USA). The online questionnaire displayed the participant information before presenting any survey questions and required participants to confirm their consent before proceeding.

All participants were informed about the study objectives, voluntary nature of participation, confidentiality procedures, and their right to decline individual questions or withdraw without prior notice or consequences for their employment or access to services. Each participant received compensation of 100 Thai baht, provided in cash for paper-based participation or through bank transfer for online participation. Bank account details required for compensation were collected separately from the questionnaire, were not linked to questionnaire responses, were accessible only to the principal investigator, and were used solely for payment. Participant information was anonymized, and geographical information was aggregated at the village level to protect confidentiality. The same confidentiality procedures were applied across all questionnaire administration methods. The online questionnaire did not collect respondent identifiers, and no personally identifiable information or precise residential addresses were disclosed in the study findings or geographical maps.

Study period and location

The cross-sectional survey was conducted from April 2024 to March 2025 in Chaiyaphum and Khon Kaen Provinces, northeastern Thailand. These provinces were purposively selected because of their substantial smallholder meat goat populations and previous documentation of *Brucella* spp. and *C. burnetii* in local goat herds [11, 12]. Participants were recruited from nine of the 16 districts in Chaiyaphum Province and 10 of the 26 districts in Khon Kaen Province (Figure 1).

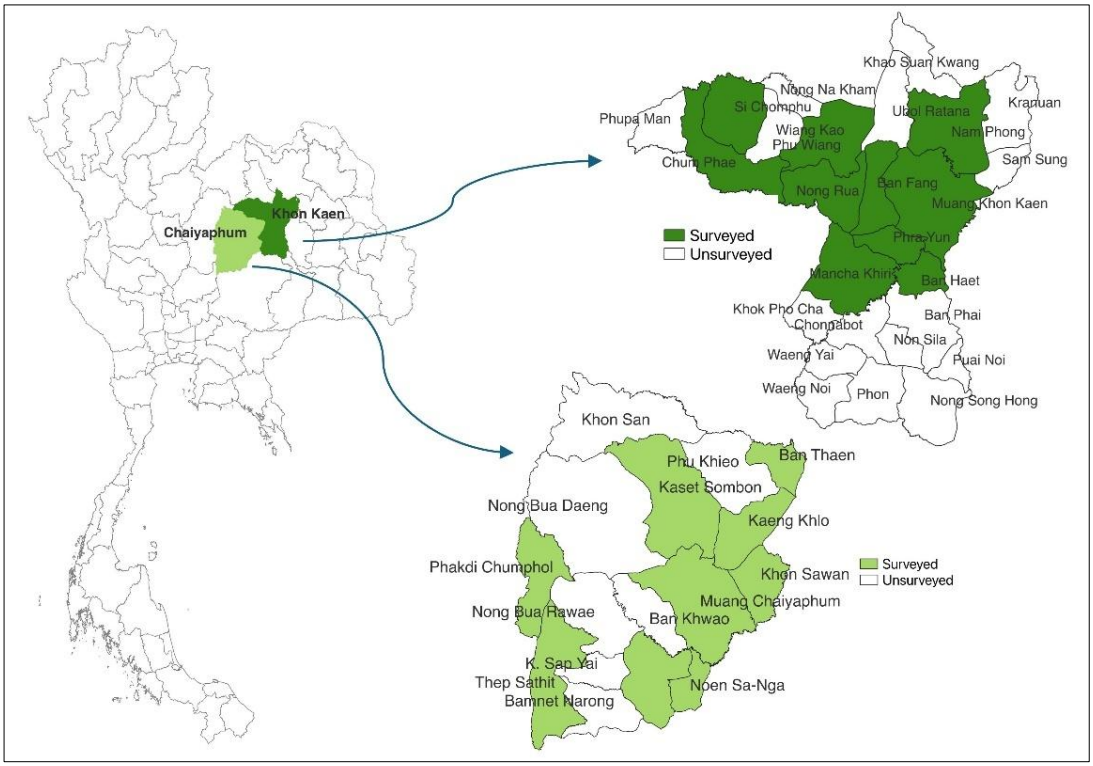


Figure 1: Districts of Chaiyaphum and Khon Kaen Provinces, northeastern Thailand, where meat goat farmers participated in the questionnaire survey. Shaded areas indicate surveyed districts, whereas unshaded areas indicate districts without participating farmers. The inset map shows the geographical locations of the two provinces within Thailand.

The geographical distribution of participating farmers was determined by the locations of members of the provincial meat goat farmers' network rather than by a predefined spatial sampling framework. Consequently, recruitment was concentrated in districts near the provincial border in Chaiyaphum, whereas participating

districts were more widely distributed throughout Khon Kaen. This distribution reflected the accessibility and voluntary participation of network members and should not be interpreted as representative geographical sampling. The numbers of participating farmers in individual districts are presented in the Results section.

Study design

An observational, cross-sectional questionnaire-based study was conducted to evaluate KAP regarding brucellosis and coxiellosis among meat goat farmers. The study also investigated demographic and herd-related factors associated with the three KAP domains and examined their direct and indirect statistical associations using regression and path analyses.

Eligible participants were adult meat goat farmers recruited through the provincial farmers' network in Chaiyaphum and Khon Kaen Provinces. Participation was voluntary, and recruitment followed a non-probability convenience sampling approach. Data were collected using a structured questionnaire administered through self-administered paper forms, interviewer-administered paper forms, or an online survey. The study was designed to assess disease-related awareness, attitudes toward prevention and control, and reported preventive behaviors without introducing an experimental intervention.

The primary units of analysis were individual farmers for sociodemographic characteristics and KAP scores and individual farms for herd-related characteristics. Because some farms contributed multiple respondents, farm identifiers were used to account for potential within-farm dependence in sensitivity analyses. The cross-sectional design permitted the identification of statistical associations but did not establish temporal relationships or causal effects.

Sampling procedures

Participants were recruited voluntarily from the meat goat farmers' network in Chaiyaphum and Khon Kaen Provinces. Network members who met the eligibility criteria and agreed to participate were enrolled through convenience sampling rather than random selection.

The estimated population of meat goat farmers across the two provinces was 2,634 [22]. The target sample size was calculated using the single-population proportion formula [23], assuming an expected proportion of satisfactory knowledge of 57.7%, based on a previous KAP investigation among small-ruminant farmers in China [15]. The calculation used a 95% confidence level (Z = 1.96) and an absolute precision of 5% (d = 0.05). After applying the finite population correction for 2,634 farmers, the required sample size was 329 participants ($n_o = 1.96^2 \times 0.577 \times 0.423/0.05^2 \approx 375.05$; $n = n_o/[1 + (n_o - 1)/N] \approx 328.4$, rounded up to 329).

A total of 146 eligible farmers participated, representing 137 farms. Of these respondents, 129 were the sole participants from their respective farms, 14 represented seven farms with two respondents each, and three were recruited from one farm. Thus, 17 respondents (11.64%) came from farms contributing more than one participant. These farms were located exclusively in Ban Thaen and Noen Sa-nga districts of Chaiyaphum Province.

To distinguish individual-level and farm-level observations, sociodemographic characteristics and KAP scores were analyzed using 146 respondents, whereas herd size, numbers of breeding bucks and does, reported clinical histories, and potential disease reservoirs were summarized for 137 farms. Farm identifiers were retained in the analytical dataset (Supplementary File S3). Regression and path models were additionally refitted using farm-clustered robust standard errors to evaluate the sensitivity of findings to within-farm dependence.

The target population comprised all 2,634 meat goat farmers in the two provinces, whereas the source population consisted of members of the provincial meat goat farmers' network. The network membership list maintained by network coordinators served as the sampling frame. The final study population comprised the 146 eligible network members who provided informed consent.

Recruitment was restricted to the one-year period specified in the approved study protocol. By the end of March 2025, no additional farmers had volunteered, so recruitment concluded without reaching the calculated target of 329 participants. Extending the recruitment period would have required an amendment to the approved protocol. Because participation was voluntary, the number of farmers informed about the study who subsequently declined participation was not recorded. Although the study initially intended to recruit one respondent per farm, multiple respondents were enrolled from eight farms.

Questionnaire development and validation

The questionnaire was developed by adapting and expanding the structured herd-level instrument used in a previous epidemiological investigation of caprine brucellosis in the same production system [11]. The original instrument assessed herd structure, management practices, reproductive history, and three aspects of farmers'

knowledge regarding disease transmission. The revised questionnaire expanded the assessment of disease-related knowledge, added an attitude component, and incorporated additional indicators of preventive practices.

The knowledge assessment included 14 scored items addressing disease awareness and transmission-related knowledge, including exposure to reproductive materials, milk and meat, urine and feces, natural mating, companion animals, rodents, and birds. Additional topics included risks during human pregnancy, subclinical infection, quarantine, kidding-pen separation, recommended testing intervals, and minimum testing age. The attitude component comprised 15 scored items concerning disease prevention and control. The practice component included 44 scored items organized into eight functional domains: animal movement, biosecurity, disease surveillance, farm certification, farm management, personal protection, reproductive management, and sanitation.

The administered questionnaire comprised four sections: personal and farm information (29 items), farm practices (48 items), attitudes toward disease prevention and control (16 items), and knowledge of prevention and control (12 items). Of the administered items, 44 practice items and 15 attitude items were retained for scoring. The knowledge score incorporated the 12 knowledge-section items and two additional disease awareness items from the personal and farm information section, resulting in 14 scored items.

The two awareness items assessed whether respondents had previously heard of brucellosis and coxiellosis. Because these items measured disease recognition rather than factual understanding, their findings were also reported separately. Nevertheless, both items were retained in the composite knowledge score to maintain consistency across analyses. The original 12-item factual knowledge score can be reconstructed from the individual-level data in Supplementary File S3.

The investigators drafted the questionnaire in Thai and collectively reviewed it for content coverage, scientific accuracy, clarity, and comprehensibility among smallholder farmers. Items adapted from the earlier instrument had previously been administered to 39 herd owners in the same provinces [11]. None of those farms participated in the present investigation. Because Thai was the first language of all respondents and interviewers, translation and back-translation were unnecessary.

Formal content validation by independent external experts and a separate pilot study of the expanded questionnaire were not conducted. Internal consistency was therefore evaluated using responses obtained during the main study. Cronbach's alpha coefficients were 0.75 for knowledge, 0.60 for attitudes, and 0.79 for practices. The attitude coefficient was below the conventional acceptability threshold of 0.70.

Inspection of attitude item statistics indicated a substantial ceiling effect, with 12 of 15 items having mean scores between 1.55 and 1.90 on a three-point scale ranging from 0 to 2. The restricted variation among respondents, together with the three-point response format selected to facilitate comprehension among participants with limited formal education [24], may have contributed to the relatively low internal consistency. Accordingly, attitude-related findings were interpreted cautiously. Exploratory factor analysis or other formal construct-validity assessments were not conducted because several attitude items exhibited minimal variability, limiting their suitability for factor extraction.

Scoring procedures and handling of missing data

Knowledge items were assigned a score of 1 for a correct response and 0 for an incorrect response, yielding a possible total score of 0–14. Items K1.9, K1.10, and K1.11 were negatively worded; therefore, a response of "False" was considered correct and assigned a score of 1.

Attitude items were scored from 0 to 2, with higher scores representing more favorable attitudes toward disease prevention and control. The maximum attainable attitude score was 30. Items A2.12 and A2.13 were negatively worded and reverse-scored so that agreement received 0 and disagreement received 2. Item A2.12 addressed the acceptability of sharing breeding bucks within the farmers' network, a practice previously associated with reproductive pathogen transmission in this production system [13]. Item A2.13 addressed the introduction of new animals into existing herds without quarantine.

Preventive practice items were scored as 1 for the recommended preventive response and 0 otherwise, yielding a possible total score of 0–44. For items P3.5 and P3.34, the response "Never" represented the preventive behavior and was therefore assigned a score of 1. Composite KAP scores were calculated as unweighted sums of the respective item scores. The complete scoring criteria, reverse-coded items, and categorical predictor reference groups are provided in Supplementary Table S2.

One attitude item requested the amount respondents were willing to pay for herd testing, expressed in Thai

baht. Because this was an open-ended numerical question rather than a Likert-scale attitude item, it was excluded from the composite attitude score. This question was unanswered by 24 respondents. No other KAP items contained missing responses; consequently, all 146 participants had complete knowledge, attitude, and practice scores. Missing-value imputation was unnecessary, and all regression and path analyses were performed using complete cases (n = 146).

Four of the 48 administered practice items (P3.4, P3.29, P3.35, and P3.37) were excluded from the composite practice score because they did not consistently represent disease prevention or biosecurity behaviors. Item P3.4 was potentially influenced by farm size, stocking density, season, and production system. Item P3.29 included a non-applicable response for farms that did not use concentrate feed. Item P3.35 primarily reflected production or marketing characteristics, whereas item P3.37 measured external exposure rather than a specific preventive behavior. Their exclusion was intended to improve the conceptual relevance of the practice score. These exclusions were decided after data collection but before the regression and path analyses, on conceptual grounds rather than on the basis of item statistics. Original questionnaire item codes were retained, resulting in gaps within the P3.1–P3.48 sequence.

Item P3.19, which assessed breeding methods, showed no variation because all respondents reported natural mating and none reported artificial insemination. Although this item did not contribute to between-respondent variability, it was retained to preserve the scoring denominator of the administered instrument. Supplementary Table S2 provides the full wording and scoring decisions for all retained and excluded items.

Data collection

Participants were eligible if they were at least 18 years old, resided in Chaiyaphum or Khon Kaen Province, had at least one year of goat farming experience, and were directly involved in meat goat production. Eligible individuals included farm owners and non-owner herd managers responsible for routine activities such as feeding, breeding, and animal health management.

Participants selected one of three approved questionnaire administration methods. The first involved self-administered paper questionnaires, which participants completed independently and deposited in designated collection boxes. The second involved interviewer-administered paper questionnaires, in which investigators read questions aloud and recorded responses. This option was provided particularly for participants who were unable to read or complete the questionnaire independently. The third method involved self-administered online questionnaires distributed through Google Forms.

Question wording, sequence, and response options were identical across all three administration methods. Of the 146 participants, 26 (17.81%) completed self-administered paper questionnaires, 100 (68.49%) completed interviewer-administered questionnaires, and 20 (13.70%) completed the online questionnaire. Interviewer administration was therefore the predominant data collection method.

Investigators administering questionnaires received standardized instructions regarding question delivery and avoidance of leading or prompting respondents. Questionnaire administration mode was recorded for each participant. Differences in KAP scores among the three administration methods were examined using the Kruskal–Wallis test, and differences in educational attainment and age among administration groups were examined using the chi-square and Kruskal–Wallis tests, respectively. Because participants independently selected their preferred administration method, the final regression models were additionally adjusted for administration mode in sensitivity analyses.

Questionnaire completion required approximately 15–20 min. Sociodemographic characteristics were categorized using predefined classifications. Farming experience was grouped as < 5 years or ≥ 5 years, with the latter representing relatively greater farming experience within the study population. However, farming duration was not considered equivalent to professional expertise because expertise depends on factors beyond accumulated experience, including sustained deliberate practice [25, 26].

Statistical analysis

Statistical analyses were performed using R version 4.6.0 (R Foundation for Statistical Computing, Vienna, Austria) through RStudio version 2026.08.2+200 (Posit PBC, Boston, MA, USA). The analysis environment included the following user-library packages: broom (1.0.13), car (3.1-5), carData (3.0-6), dplyr (1.2.1), effectsize (1.0.3), flextable (0.10.0), forcats (1.0.1), ggplot2 (4.0.3), gtsummary (2.5.1), lavaan (0.6-21), lubridate (1.9.5), lmtest (0.9-40), performance (0.18.1), psych (2.6.5), purrr (1.2.2), ragg (1.5.2), readr (2.2.0), readxl (1.5.0), sandwich (3.1-2), stringr (1.6.0), systemfonts (1.3.2), tibble (3.3.1), tidyr (1.3.2), tidyverse (2.0.0), and zoo (1.8-15). System-library

packages included base (4.6.0), boot (1.3-32), datasets (4.6.0), graphics (4.6.0), grDevices (4.6.0), methods (4.6.0), stats (4.6.0), and utils (4.6.0).

Descriptive statistics summarized participants' sociodemographic characteristics, herd information, reported clinical histories, and potential disease reservoirs. Categorical variables are expressed as frequencies and percentages [n (%)]. Continuous variables exhibiting non-normal distributions were summarized using medians and interquartile ranges [IQR; median (Q1–Q3)], with normality assessed using the Shapiro–Wilk test.

Multiple linear regression analysis

Multiple linear regression was performed to identify demographic and herd-related factors associated with knowledge, attitude, and practice scores. Because each outcome was a continuous composite score, linear regression was used instead of logistic regression. Associations are expressed as unstandardized regression coefficients with 95% confidence intervals (CIs).

Candidate explanatory variables included sex, age, educational attainment (bachelor's degree or higher versus lower educational attainment), farming experience (≥ 5 years versus < 5 years), province, reported herd histories of abortion, sterility, orchitis, arthritis, and weak-born kids, and reported illness among family members. Farming objectives, herd size, and reported presence of dogs, cats, rats, birds, ticks, and squirrels were summarized descriptively but were not included as candidate predictors in the regression models.

Predictor selection was performed using bidirectional stepwise selection based on the Akaike information criterion (AIC). Because automated variable selection may produce unstable models and optimistic coefficient estimates, the resulting models were interpreted as exploratory rather than confirmatory. This approach was adopted because previous evidence was insufficient to establish a restricted set of predictors specific to the study population.

Educational attainment was dichotomized because the original five-category specification included a reference group of only seven participants, potentially compromising model stability. Female sex, residence in Khon Kaen Province, and absence of the respective reported clinical signs served as reference categories. Complete reference-category definitions are provided in Supplementary Table S2.

Model performance was evaluated using adjusted coefficients of determination (adjusted R^2). Regression assumptions were assessed through the Shapiro–Wilk test for residual normality, the Breusch–Pagan test for homoscedasticity, and Cook's distance for influential observations. Multicollinearity was evaluated using variance inflation factors (VIFs), with values > 5 indicating potentially important collinearity.

Correlation analysis

Associations among knowledge, attitude, and practice scores were evaluated after examining the linearity of each pairwise relationship. Pearson's correlation coefficient was used to assess the knowledge–attitude relationship, whereas Spearman's rank correlation coefficient was applied to the knowledge–practice and attitude–practice relationships. The correlation method was selected according to the observed characteristics of each relationship.

Path analysis

Path analysis was performed using the lavaan package (version 0.6-21) in R to evaluate direct and indirect associations among demographic characteristics, herd-related factors, and KAP scores. A fully recursive model containing observed variables without latent constructs was estimated using maximum likelihood with complete-case data.

Knowledge, attitude, and practice scores were specified as endogenous variables. Exogenous variables included graduate education, reported illness in a family member, reported herd histories of abortion, arthritis, sterility, and orchitis, farming experience of ≥ 5 years, male sex, and residence in Chaiyaphum Province. All exogenous variables were represented as binary indicators.

The hypothesized model specified knowledge as a predictor of both attitudes and preventive practices and attitudes as a predictor of preventive practices. Accordingly, the model permitted estimation of the direct knowledge–practice association and the indirect association through attitudes. The indirect association was explicitly defined as the product of the knowledge–attitude and attitude–practice coefficients, and the total association as the sum of the direct and indirect associations; their 95% CIs were estimated using nonparametric bootstrapping (percentile and bias-corrected intervals). Because of the cross-sectional design, these estimates represent a statistical decomposition of associations rather than causal mediation effects. No residual covariances

were freely estimated.

Unstandardized path coefficients were reported with standard errors and 95% Wald CIs, with standardized coefficients presented where applicable. The complete lavaan model specification and analysis script are provided in Supplementary File S4.

Given the modest sample size for structural modeling [27], the stability of the three coefficients connecting the KAP domains was examined using nonparametric case bootstrapping with 5,000 resamples and a random seed of 20260905. Percentile bootstrap CIs were reported alongside Wald CIs.

Overall model fit was assessed using the chi-square (χ^2) test, comparative fit index (CFI), Tucker–Lewis index (TLI), root mean square error of approximation (RMSEA) with its 90% CI, and standardized root mean square residual (SRMR) [28–30]. Prespecified acceptable fit criteria were CFI > 0.90 [29], RMSEA < 0.08 [28], and SRMR < 0.08 [29]. The RMSEA test of close-fit (H_0: RMSEA ≤ 0.05) and model modification indices were additionally examined to assess global fit and identify potential localized model misspecification.

All statistical tests were two-tailed, with $p < 0.05$ considered statistically significant. The path model included a restricted set of binary exogenous variables to maintain a manageable number of estimated parameters (17 free parameters: 14 regression coefficients and three residual variances, with exogenous variables treated as fixed) relative to the sample size. Consequently, the predictor sets used in the regression models and the path model differed, and their coefficients were not directly interchangeable.

Epidemiological analysis

The geographical distribution of participating farms was visualized using QGIS version 3.36 (QGIS Development Team, Switzerland). Spatial distribution maps illustrated the study locations across Khon Kaen and Chaiyaphum Provinces, northeastern Thailand.

RESULTS

Sociodemographic characteristics of the farmers

A total of 146 meat goat farmers participated in the study, including 95 (65.07%) from Khon Kaen Province and 51 (34.93%) from Chaiyaphum Province. Participants from Khon Kaen were recruited from Ban Fang (n = 1), Ban Haet (n = 1), Chum Phae (n = 1), Mancha Khiri (n = 10), Mueang Khon Kaen (n = 7), Nam Phong (n = 5), Nong Ruea (n = 25), Phra Yuen (n = 13), Phu Wiang (n = 4), and Si Chomphu (n = 28). Participants from Chaiyaphum were recruited from Ban Thaen (n = 31), Chatturat (n = 1), Kaeng Khro (n = 4), Kaset Sombun (n = 3), Khon Sawan (n = 2), Mueang Chaiyaphum (n = 1), Noen Sa-nga (n = 7), Phakdi Chumphon (n = 1), and Thep Sathit (n = 1). Recruitment varied across districts, with participation ranging from 1 to 31 farmers per district.

The study population comprised 74 men (50.68%) and 72 women (49.32%), with a median age of 53 years (IQR: 44–59 years). Most participants were involved in both breeding and fattening (n = 104; 71.23%), followed by fattening only (n = 27; 18.49%) and breeding only (n = 15; 10.27%). The median farming experience was 4 years (IQR: 3–6 years), and the median herd size was 36 goats (IQR: 18–55 goats).

Regarding educational attainment, 60 participants (41.10%) had completed primary school, 46 (31.51%) had completed secondary school, 22 (15.07%) held graduate degrees, 11 (7.53%) held bachelor's degrees, and seven (4.79%) had no formal education (Table 1).

History of clinical signs and potential disease reservoirs

Weak-born kids were the most frequently reported clinical manifestation, identified by 103 respondents (70.55%), followed by abortion (n = 76; 52.05%), arthritis (n = 62; 42.47%), sterility (n = 48; 32.88%), and orchitis (n = 30; 20.55%). These findings represent farmer-reported histories rather than laboratory-confirmed infections. Although the reported manifestations may occur in animals affected by brucellosis or coxiellosis, they are not specific to either disease, and no diagnostic confirmation was performed in the present study.

A history of illness in a family member was reported by 32 respondents (21.92%). Because these illnesses were self-reported and not clinically confirmed, they could not be attributed to zoonotic transmission.

At the farm level (n = 137), weak-born kids were reported on 94 farms (68.61%), abortion on 70 (51.09%), arthritis on 57 (41.61%), sterility on 43 (31.39%), and orchitis on 29 (21.17%). Dogs and rats were the most frequently reported animals potentially associated with pathogen maintenance or transmission within or around goat herds, followed by birds, cats, squirrels, and ticks (Table 2). Their reported presence did not establish their infection status or involvement in pathogen transmission.

Table 1: Sociodemographic and farm characteristics of meat goat farmers in Khon Kaen and Chaiyaphum Provinces, northeastern Thailand (N = 146).

Characteristic	Value
Sex	
Female	72 (49.32)
Male	74 (50.68)
Age (years), median (Q1–Q3)	53 (44–59)
Province	
Khon Kaen	95 (65.07)
Chaiyaphum	51 (34.93)
Farming objective	
Breeding	15 (10.27)
Fattening	27 (18.49)
Both breeding and fattening	104 (71.23)
Goat population (head), median (Q1–Q3)	36 (18–55)
Farming experience (years), median (Q1–Q3)	4 (3–6)
< 5 years	78 (53.42)
≥ 5 years	68 (46.58)
Educational attainment	
No formal education	7 (4.79)
Primary school	60 (41.10)
Secondary school	46 (31.51)
Bachelor's degree	11 (7.53)
Graduate degree	22 (15.07)

Categorical variables are presented as numbers (percentages), and continuous variables are presented as median (first quartile–third quartile). N = number of respondents; Q1 = first quartile; Q3 = third quartile. The goat population represents the number of goats per participating farm.

Table 2: Farmer-reported history of clinical signs and presence of potential disease reservoirs in meat goat herds.

Characteristic	Respondents, n (%) (N = 146)	Farms, n (%) (N = 137)
Reported history of clinical signs in goats		
Abortion	76 (52.05)	70 (51.09)
Sterility	48 (32.88)	43 (31.39)
Orchitis	30 (20.55)	29 (21.17)
Arthritis	62 (42.47)	57 (41.61)
Weak-born kids	103 (70.55)	94 (68.61)
Reported illness in a family member	32 (21.92)	Not applicable
Reported presence of potential reservoirs		
Dogs	101 (69.66)[a]	94 (69.12)
Cats	48 (32.88)	47 (34.31)
Rats	101 (69.18)	94 (68.61)
Birds	84 (57.53)	81 (59.12)
Ticks	38 (26.03)	33 (24.09)
Squirrels	42 (28.77)	39 (28.47)

N = total number of respondents or farms; n = number reporting the characteristic. [a]Data on the presence of dogs were unavailable for one respondent (n = 145) and the corresponding farm (n = 136 farms). All other farm-level percentages were calculated using 137 farms. Clinical histories and potential reservoir presence are farm level characteristics; therefore, the farm level column provides the appropriate denominator for these variables. Illness in a family member is a respondent level characteristic. Laboratory testing did not confirm reported clinical signs, and the presence of potential reservoirs does not indicate confirmed pathogen carriage.

Overall KAP

The distributions of knowledge, attitude, and practice scores are presented in Figures 2–4. The mean knowledge score was 9.32 of 14 (66.54%; 95% CI: 63.43–69.64), whereas the mean attitude score was 24.48 of 30 (81.60%; 95% CI: 79.57–83.63). In contrast, the mean preventive practice score was 22.47 of 44 (51.07%; 95% CI: 48.79–53.36), indicating a substantial discrepancy between favorable attitudes and reported preventive practices.

Disease awareness differed markedly between the two infections. Only four farmers (2.74%) reported having heard of coxiellosis or Q fever, compared with 63 (43.15%) who had heard of brucellosis. These awareness items were included in the composite knowledge score but were also evaluated separately because they assessed disease recognition rather than factual understanding.

Preventive practice scores varied across functional domains. Farm certification (30.82%) and animal movement (31.10%) had the lowest proportions of recommended preventive responses, whereas farm management (72.83%) and personal protection (67.38%) had the highest.

Knowledge and practice scores differed significantly among questionnaire administration methods. The Kruskal–Wallis test identified differences in knowledge (H = 9.87, degrees of freedom [df] = 2, p = 0.007) and practices (H = 11.92, df = 2, p = 0.003), but not attitudes (H = 4.54, df = 2, p = 0.103).

Online respondents had the highest mean knowledge score (11.00 of 14; 78.57%) and practice score (26.65 of 44; 60.57%). Corresponding scores were 9.04 (64.57%) and 21.50 (48.86%) among interviewer-administered respondents and 9.08 (64.84%) and 23.00 (52.27%) among self-administered paper respondents.

The composition of the administration groups differed substantially. Graduate degrees were held by 65.00% of online respondents, compared with 11.54% of self-administered paper respondents and 6.00% of interviewer-administered respondents ($\chi^2 = 51.12$, df = 8, $p < 0.001$). Median ages were 44.0, 36.5, and 56.0 years, respectively (H = 66.03, df = 2, $p < 0.001$). Consequently, the observed score differences could not be attributed solely to questionnaire administration mode because educational attainment and age also differed across groups.

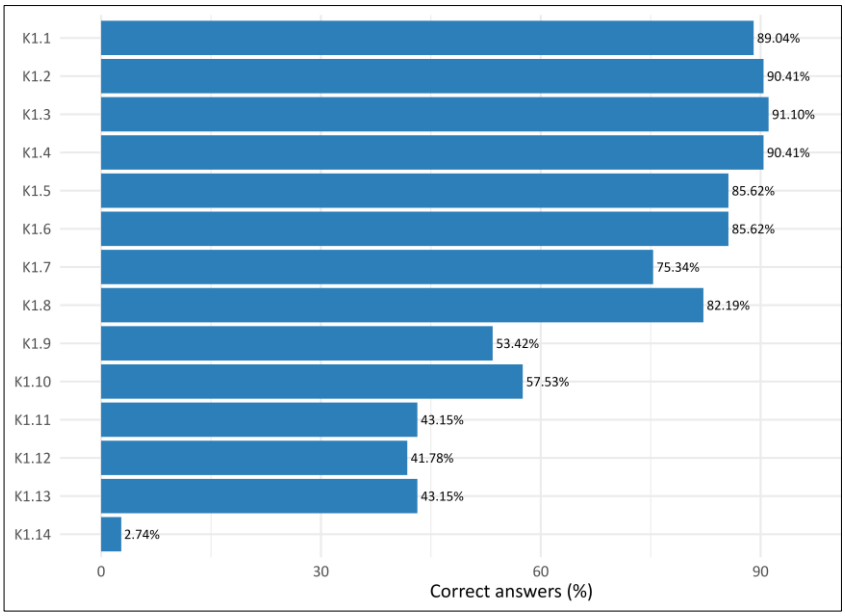


Figure 2: Percentage of correct responses to individual knowledge items concerning brucellosis and coxiellosis among meat goat farmers in northeastern Thailand (N = 146). Items K1.1–K1.14 are described in Supplementary Table S1. Items K1.13 and K1.14 assess previous awareness of brucellosis and coxiellosis, respectively, rather than factual disease knowledge.

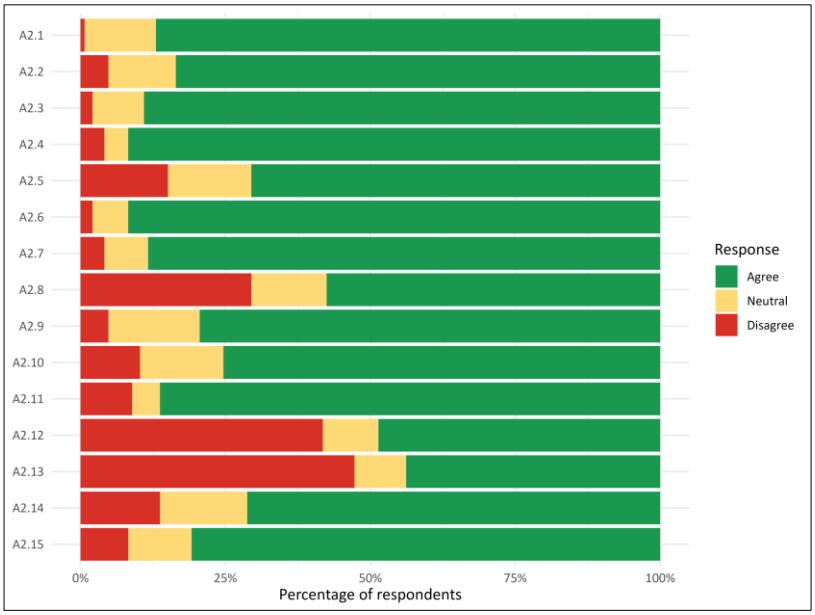


Figure 3: Distribution of responses to individual attitude items concerning brucellosis and coxiellosis prevention and control among meat goat farmers in northeastern Thailand (N = 146). Responses are categorized as agree, neutral, or disagree using a three-point scale. Items A2.1–A2.15 are described in Supplementary Table S1. Items A2.12 and A2.13 are negatively worded, and agreement indicates a less favorable preventive attitude. Their scoring directions were reversed for composite score calculation, whereas the figure presents the original responses.

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Figure 4: Distribution of responses to preventive practice items concerning brucellosis and coxiellosis among meat goat farmers in northeastern Thailand (N = 146). Items are grouped into eight domains: animal movement, biosecurity, disease surveillance, farm certification, farm management, personal protection, reproductive management, and sanitation. Responses are categorized as usually/correct or never/incorrect. Item codes P3.1–P3.48 are defined in Supplementary Table S1. Item P3.19 showed no variation because all respondents reported the same breeding method.

Internal consistency of the questionnaire

Cronbach's alpha coefficients were 0.75 for the 14-item knowledge domain, 0.60 for the 15-item attitude domain, and 0.79 for the 44-item practice domain. Reverse-scoring the two negatively worded attitude items (A2.12 and A2.13) increased the attitude coefficient from 0.51 to 0.60.

Excluding practice item P3.19, which exhibited no between-respondent variation, did not alter the overall practice coefficient. Internal consistency estimates for individual practice domains ranged from 0.29 for farm management (three items) to 0.80 for farm certification (two items). Because several domains contained few items addressing distinct preventive behaviors rather than a single underlying construct, the overall practice

coefficient was retained as the principal reliability estimate. The relatively low attitude coefficient indicated limited internal consistency and warranted cautious interpretation of attitude-related findings.

Factors associated with KAP

Multiple linear regression identified several demographic and herd-related characteristics associated with KAP scores (Table 3).

For knowledge, participants with a bachelor's degree or higher scored 1.56 points higher than those with lower educational attainment (95% CI: 0.61–2.52, p = 0.002). Residence in Chaiyaphum Province was associated with a 1.36-point higher knowledge score than residence in Khon Kaen Province (95% CI: 0.50–2.22, p = 0.002). Conversely, a reported history of illness in a family member was associated with a 1.79-point lower knowledge score (95% CI: −2.78 to −0.79, p < 0.001). The model had an AIC of 680.54 and an adjusted R^2 of 0.176.

For attitudes, reported histories of arthritis (b = 2.45, 95% CI: 1.18–3.73, p < 0.001) and sterility (b = 1.83, 95% CI: 0.53–3.12, p = 0.006) in the herd were positively associated with attitude scores. Having a bachelor's degree or higher was also positively associated with attitudes (b = 1.54, 95% CI: 0.18–2.91, p = 0.027). In contrast, a reported history of orchitis was negatively associated with attitude scores (b = −1.71, 95% CI: −3.34 to −0.08, p = 0.040). The model had an AIC of 785.40 and an adjusted R^2 of 0.153.

For preventive practices, higher scores were associated with a bachelor's degree or higher (b = 3.39, 95% CI: 1.08–5.70, p = 0.004), farming experience of ≥ 5 years (b = 2.57, 95% CI: 0.56–4.57, p = 0.012), residence in Chaiyaphum Province (b = 2.29, 95% CI: 0.19–4.38, p = 0.033), and a reported history of arthritis in the herd (b = 4.00, 95% CI: 1.95–6.04, p < 0.001). A reported history of abortion was negatively associated with practice scores (b = −2.61, 95% CI: −4.66 to −0.55, p = 0.013). The model had an AIC of 924.93 and an adjusted R^2 of 0.201.

The adjusted R^2 values indicated that the included predictors explained approximately 15%–20% of the variation in the three KAP scores. Predictors that did not meet the prespecified significance threshold are presented in Table 3 without interpretation as borderline associations.

Table 3: Multiple linear regression analysis of demographic and herd-related factors associated with knowledge, attitude, and preventive practice scores regarding brucellosis and coxiellosis among meat goat farmers (N = 146).

Model/predictor	b	SE	95% CI	p-value
Knowledge (adjusted R^2 = 0.176; AIC = 680.54)				
Bachelor's degree or higher	1.56	0.48	0.61–2.52	0.002*
Chaiyaphum Province	1.36	0.44	0.50–2.22	0.002*
History of sterility in the herd	0.84	0.43	−0.01 to 1.68	0.053
History of illness in family	−1.79	0.50	−2.78 to −0.79	< 0.001*
Attitude (adjusted R^2 = 0.153; AIC = 785.40)				
Male	−0.93	0.57	−2.06 to 0.21	0.110
Bachelor's degree or higher	1.54	0.69	0.18–2.91	0.027*
History of sterility in the herd	1.83	0.66	0.53–3.12	0.006*
History of orchitis in the herd	−1.71	0.82	−3.34 to −0.08	0.040*
History of arthritis in the herd	2.45	0.64	1.18–3.73	< 0.001*
History of illness in family	−0.99	0.71	−2.39 to 0.42	0.166
Practice (adjusted R^2 = 0.201; AIC = 924.93)				
Age (years)	−0.06	0.04	−0.14 to 0.03	0.169
Bachelor's degree or higher	3.39	1.17	1.08–5.70	0.004*
Farming experience ≥ 5 years	2.57	1.01	0.56–4.57	0.012*
Chaiyaphum Province	2.29	1.06	0.19–4.38	0.033*
History of abortion in the herd	−2.61	1.04	−4.66 to −0.55	0.013*
History of arthritis in the herd	4.00	1.03	1.95–6.04	< 0.001*
History of weak-born kids	−2.40	1.24	−4.84 to 0.05	0.055
History of illness in family	−1.77	1.20	−4.14 to 0.59	0.141

N = number of respondents; b = unstandardized regression coefficient; SE = standard error; CI = confidence interval; AIC = Akaike information criterion; R^2 = coefficient of determination. Reference categories were educational attainment below a bachelor's degree, female sex, residence in Khon Kaen Province, and absence of the respective reported clinical history. Regression intercepts are omitted. *p < 0.05. Outcomes were continuous summed scores; therefore, coefficients represent adjusted differences in score points rather than odds ratios.

Regression model diagnostics

VIFs were below 1.6 across all regression models, with a maximum of 1.51, indicating no appreciable multicollinearity. The earlier five-category education specification, which produced a VIF of 5.74 because of a small reference group, was replaced by the binary education variable.

Residuals of the practice model were consistent with normality (Shapiro–Wilk W = 0.99, p = 0.772). However,

the knowledge (W = 0.96, p < 0.001) and attitude (W = 0.98, p = 0.045) models showed departures from normality. These departures should be considered when interpreting inference from the fitted linear models. Alternative model specifications were not fitted; however, given the sample size (n = 146) and the mild departures (W ≥ 0.96), inference was considered approximately valid, and the farm-clustered robust (sandwich) standard errors used in the sensitivity analyses, which do not assume normally distributed homoscedastic errors, yielded conclusions consistent with the primary analysis for most associations.

The Breusch–Pagan test did not indicate significant heteroscedasticity in any model (p = 0.135, 0.214, and 0.188). Maximum Cook's distances were 0.06, 0.10, and 0.07 for the knowledge, attitude, and practice models, respectively, suggesting no single observation exerted excessive influence according to the reported diagnostic criterion.

Sensitivity analysis accounting for farm-level clustering

Because 17 respondents (11.64%) were recruited from farms contributing multiple participants, the regression and path models were refitted using cluster-robust standard errors at the farm level (137 clusters).

In the knowledge model, all associations identified in the primary analysis remained statistically significant after clustering, including educational attainment (p < 0.001), residence in Chaiyaphum Province (p = 0.008), and reported illness in a family member (p = 0.003).

In the attitude model, educational attainment (p = 0.026), reported sterility (p = 0.010), and reported arthritis (p < 0.001) remained significant. However, the association with reported orchitis was no longer statistically significant (b = −1.71, 95% CI: −3.53 to 0.12, p = 0.067).

In the practice model, educational attainment (p = 0.015), farming experience of ≥ 5 years (p = 0.030), reported abortion (p = 0.029), and reported arthritis (p = 0.002) remained significant. The association with residence in Chaiyaphum Province was attenuated and no longer met the significance threshold (b = 2.29, 95% CI: −0.28 to 4.86, p = 0.081).

In the path model, the association between reported orchitis and attitudes was no longer statistically significant (p = 0.082). Conversely, graduate education became statistically significant in its association with attitudes (b = 1.49, 95% CI: 0.05–2.92, p = 0.042), although the primary analysis had not met the significance threshold (p = 0.053). This change was not interpreted as evidence of a substantive association because it resulted from a small change in the standard error of an estimate near the threshold.

All three coefficients linking the KAP domains retained their directions and statistical significance after accounting for clustering. Knowledge remained associated with attitudes (p < 0.001) and practices (b = 0.37, 95% CI: 0.04–0.71, p = 0.027), while attitudes remained associated with practices (b = 0.54, 95% CI: 0.27–0.81, p < 0.001). Complete sensitivity analysis results are provided in Supplementary Table S5.2.

Sensitivity analysis accounting for questionnaire administration mode

Because questionnaire administration mode was not randomly assigned, the regression models and the practice equation of the path model were additionally adjusted for administration mode while retaining farm-clustered robust standard errors.

Compared with interviewer-administered questionnaires, online administration was associated with higher knowledge scores (b = 0.93, 95% CI: 0.03–1.82, p = 0.043), but not with attitude (p = 0.133) or practice scores (p = 0.068) in the regression models. However, in the practice equation of the path model, online administration was associated with higher practice scores after adjustment for knowledge and attitudes (b = 3.67, 95% CI: 0.71–6.64, p = 0.016). Self-administered paper questionnaires were not significantly associated with any KAP score relative to interviewer administration.

In the knowledge model, educational attainment (p = 0.003), residence in Chaiyaphum Province (p = 0.010), and reported illness in a family member (p = 0.004) remained significant after adjustment for administration mode.

In the attitude model, reported arthritis (p < 0.001) and sterility (p = 0.011) remained significant, whereas educational attainment (b = 1.07, 95% CI: −0.39 to 2.53, p = 0.150) and reported orchitis (b = −1.59, 95% CI: −3.36 to 0.19, p = 0.080) no longer met the significance threshold.

In the practice model, reported arthritis (p < 0.001) and abortion (p = 0.041) remained significant. Farming experience (p = 0.063), residence in Chaiyaphum Province (p = 0.138), and educational attainment (p = 0.126) were no longer statistically significant. Reported weak-born kids became negatively associated with practice scores (b = −2.64, 95% CI: −5.09 to −0.18, p = 0.035), although this association was not significant in the primary

analysis and was not considered a robust finding.

Educational attainment and questionnaire administration mode were strongly associated, as 65.00% of online respondents held graduate degrees. Consequently, their independent associations could not be reliably distinguished in this sample.

In the mode-adjusted path model, the attitude–practice association remained significant (b = 0.52, 95% CI: 0.25–0.79, p < 0.001), whereas the direct knowledge–practice association was attenuated and no longer statistically significant (b = 0.27, 95% CI: −0.09 to 0.62, p = 0.139). Complete estimates are presented in Supplementary Table S5.3.

Correlations among knowledge, attitude, and practice scores

Knowledge and attitude scores were moderately and positively correlated (Pearson's r = 0.36, p < 0.001). Knowledge and practice scores showed a weak positive correlation (Spearman's ρ = 0.28, p < 0.001), whereas attitudes and practices showed a positive correlation of ρ = 0.39 (p < 0.001). All three pairwise associations were statistically significant (Table 4).

Table 4: Correlations among knowledge, attitude, and preventive practice scores regarding brucellosis and coxiellosis among meat goat farmers (N = 146).

Variable	Knowledge	Attitude	Practice
Knowledge	1.00		
Attitude	0.36*	1.00	
Practice	0.28*	0.39*	1.00

N = number of respondents. Pearson's correlation coefficient (r) was used for the knowledge–attitude association. Spearman's rank correlation coefficient (ρ) was used for the knowledge–practice and attitude–practice associations because the corresponding relationships did not satisfy the assumptions required for Pearson's correlation. *p < 0.05.

Path analysis of demographic and herd-related factors associated with KAP

Path analysis was performed to examine direct and indirect associations among demographic characteristics, reported herd health histories, and KAP scores (Figure 5 and Table 5).

Table 5: Path analysis estimates of associations among demographic characteristics, reported herd health histories, and KAP scores among meat goat farmers (N = 146).

Outcome/predictor	b	SE	95% CI	Bootstrap 95% CI	p-value
Knowledge					
Graduate degree	1.49	0.57	0.37–2.61	—	0.009*
History of illness in family	−1.71	0.51	−2.70 to −0.71	—	< 0.001*
Chaiyaphum Province	1.36	0.44	0.50–2.22	—	0.002*
Attitude					
History of arthritis in the herd	2.49	0.58	1.35–3.62	—	< 0.001*
History of sterility in the herd	1.34	0.60	0.16–2.52	—	0.026*
History of orchitis in the herd	−1.51	0.76	−2.99 to −0.03	—	0.046*
Graduate degree	1.48	0.77	−0.02 to 2.99	—	0.053
Male	−0.96	0.53	−2.00 to 0.07	—	0.067
Knowledge	0.44	0.10	0.24–0.64	0.24–0.67	< 0.001*
Practice					
Farming experience ≥ 5 years	1.26	0.89	−0.48 to 3.00	—	0.155
History of arthritis in the herd	2.82	0.97	0.92–4.71	—	0.004*
History of abortion in the herd	−3.13	0.92	−4.93 to −1.32	—	< 0.001*
Knowledge	0.37	0.18	0.03–0.72	0.06–0.69	0.033*
Attitude	0.54	0.13	0.29–0.80	0.30–0.79	< 0.001*

N = number of respondents; KAP = knowledge, attitudes, and practices; b = unstandardized path coefficient; SE = standard error; CI = confidence interval; χ^2 = chi-square statistic; df = degrees of freedom; CFI = comparative fit index; TLI = Tucker–Lewis index; RMSEA = root mean square error of approximation; SRMR = standardized root mean square residual; R^2 = coefficient of determination. Wald CIs were calculated as b ± 1.96 × SE. Bootstrap CIs are percentile intervals derived from 5,000 case resamples for the three coefficients linking KAP domains. Standardized coefficients are provided in Supplementary Table S5.1. Model fit: χ^2 = 18.10, df = 16, p = 0.318; χ^2/df = 1.13; CFI = 0.980; TLI = 0.963; RMSEA = 0.030 (90% CI: 0.000–0.085; close-fit p = 0.663); SRMR = 0.031; baseline χ^2 = 137.80, df = 30. R^2 (adjusted R^2): knowledge = 0.156 (0.139), attitude = 0.273 (0.242), and practice = 0.275 (0.249). Indirect knowledge–practice association through attitudes: b = 0.24 (bootstrap 95% CI: 0.11–0.42); total association: b = 0.62 (bias-corrected bootstrap 95% CI: 0.28–0.95). Indirect and total associations and the proportion of the indirect association (approximately 39%) were calculated from unrounded estimates; displayed values may not sum exactly because of rounding. Reference categories correspond to those specified in Table 3. *p < 0.05.

After adjustment for the specified demographic and herd-related variables, knowledge was positively associated with attitudes (b = 0.44, 95% CI: 0.24–0.64, p < 0.001) and preventive practices (b = 0.37, 95% CI: 0.03–

0.72, p = 0.033). Attitudes were also independently associated with preventive practices (b = 0.54, 95% CI: 0.29–0.80, p < 0.001).

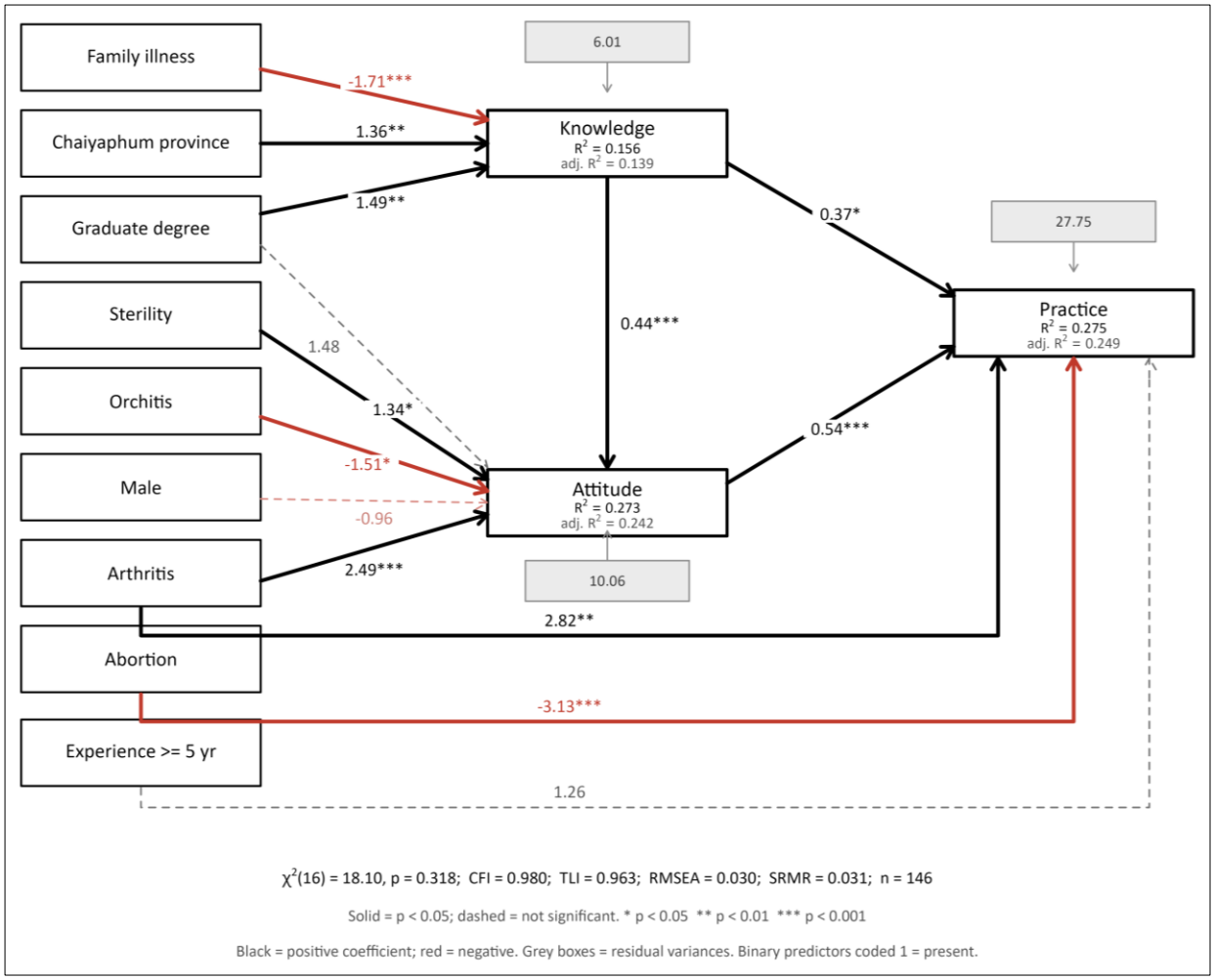


Figure 5: Path model illustrating associations among demographic characteristics, reported herd health histories, and KAP scores among meat goat farmers in northeastern Thailand (N = 146 respondents representing 137 farms). Values displayed on arrows represent unstandardized path coefficients. Red arrows indicate negative associations, whereas solid arrows represent statistically significant associations ($p < 0.05$). Dashed gray and red arrows indicate nonsignificant associations. Gray boxes adjacent to endogenous variables display residual variances; R^2 and adjusted R^2 are shown within the endogenous variable boxes. Binary variables representing reported clinical histories and illness in a family member were recoded as 1 = present, whereas the original dataset coded 0 = present. Farming experience was categorized as ≥ 5 years versus < 5 years. Model fit: $\chi^2(16) = 18.10$, $p = 0.318$; CFI = 0.980; TLI = 0.963; RMSEA = 0.030 (90% CI: 0.000–0.085; close-fit p = 0.663); SRMR = 0.031. KAP = knowledge, attitudes, and practices; N = number of respondents; χ^2 = chi-square statistic; CFI = comparative fit index; TLI = Tucker–Lewis index; RMSEA = root mean square error of approximation; SRMR = standardized root mean square residual; R^2 = coefficient of determination. *p < 0.05; **p < 0.01; ***p < 0.001. Arrows represent hypothesized statistical relationships and do not establish causality or temporal ordering because the study used a cross-sectional design.

The estimated indirect association between knowledge and preventive practices through attitudes was 0.24 (percentile bootstrap 95% CI: 0.11–0.42; bias-corrected 95% CI: 0.11–0.44), accounting for approximately 39% of the total estimated association (b = 0.62, bias-corrected bootstrap 95% CI: 0.28–0.95). The proportion was calculated from unrounded estimates; therefore, the displayed direct (0.37) and indirect (0.24) estimates do not sum exactly to the total because of rounding. These findings were consistent with the hypothesized sequential KAP structure, although the cross-sectional design did not establish causal mediation.

Bootstrap analysis using 5,000 resamples showed consistent directions and statistical significance for the three KAP-related coefficients. The percentile bootstrap 95% CIs were 0.06–0.69 for knowledge–practice, 0.30–0.79 for attitude–practice, and 0.24–0.67 for knowledge–attitude associations. All bootstrap resamples converged.

Among the demographic and herd-related variables, graduate education and residence in Chaiyaphum Province were positively associated with knowledge scores, whereas reported illness in a family member was

negatively associated with knowledge. Reported arthritis was positively associated with both attitudes and preventive practices, and reported sterility was positively associated with attitudes. In contrast, reported orchitis was negatively associated with attitudes, and reported abortion was negatively associated with preventive practices.

The path model explained 15.60% of the variance in knowledge, 27.30% in attitudes, and 27.50% in preventive practices. Corresponding adjusted R^2 values were 0.139, 0.242, and 0.249, respectively.

Farm-clustered sensitivity analyses did not change the direction or statistical significance of the associations linking the three KAP domains. However, the association between reported orchitis and attitudes was no longer statistically significant, whereas graduate education became significant in its association with attitudes. Detailed estimates are provided in Supplementary Table S5.2.

Path model fit

The model demonstrated acceptable fit according to the prespecified criteria. The chi-square test was not statistically significant ($\chi^2 = 18.10$, df = 16, p = 0.318). The CFI (0.980) and TLI (0.963) exceeded the threshold of 0.90. The RMSEA was 0.030 (90% CI: 0.000–0.085), with a nonsignificant test of close-fit (p = 0.663), while the SRMR was 0.031.

The baseline model yielded $\chi^2 = 137.80$ with 30 degrees of freedom. Modification indices did not indicate a substantial omitted parameter. The largest modification index was 5.95 for a residual covariance between knowledge and practice, followed by 3.58 for a direct path from practice to knowledge and 3.49 for a direct path from reported herd sterility to knowledge. All remaining modification indices were below 3 (Supplementary Table S5.4).

Although the observed fit indices supported the specified covariance structure, they did not establish the temporal or causal direction of the modeled relationships.

Differences between regression and path model estimates

Farming experience of ≥ 5 years was positively associated with preventive practices in the multiple regression model (b = 2.57, p = 0.012; Table 3) but not in the path model (b = 1.26, p = 0.155; Table 5).

The two models included different covariate structures. The regression model adjusted for reported histories of weak-born kids and family illness and included educational attainment as a direct predictor of practices. In contrast, the path model included educational attainment as a predictor of knowledge and additionally adjusted the practice equation for knowledge and attitudes.

Consequently, the estimated association between farming experience and preventive practices decreased from 2.57 to 1.26 points, and its CI included zero in the path model. These estimates should therefore be interpreted within their respective model specifications rather than considered directly interchangeable.

DISCUSSION

Knowledge–practice gaps and the contribution of the study

This study evaluated KAP regarding brucellosis and coxiellosis among 146 meat goat farmers in northeastern Thailand and examined demographic and herd-related factors associated with these domains. Studies that jointly investigate KAP for both infections among meat goat farmers remain scarce, particularly in Southeast Asia, where small-ruminant production continues to expand [7, 15, 19]. This investigation adds to the evidence by evaluating both diseases in a region where their causative pathogens have previously been detected and by using path analysis to distinguish direct knowledge–practice associations from indirect associations operating through attitudes. This analytical approach provides additional insight into the relationships among KAP domains beyond conventional descriptive assessments.

The findings revealed a substantial discrepancy between favorable attitudes toward disease prevention (81.60%) and implementation of recommended preventive practices (51.07%), despite a moderate knowledge score (66.54%). This pattern indicates that favorable attitudes and disease-related knowledge do not necessarily correspond to consistent adoption of preventive measures. The observed knowledge–practice gap is particularly relevant to smallholder production systems, where disease prevention may depend on farmers' access to veterinary services, diagnostic facilities, financial resources, and appropriate biosecurity infrastructure.

Differences in awareness and prevention of brucellosis and coxiellosis

Although the questionnaire evaluated brucellosis and coxiellosis together, it placed greater emphasis on

brucellosis-related preventive measures, including periodic herd testing and brucellosis-free farm certification. This emphasis reflects Thailand's existing disease control framework, in which organized surveillance, herd testing, and certification programs primarily address brucellosis, whereas the current regulations do not specify equivalent routine testing, certification, or animal movement control requirements for *C. burnetii* [11, 16, 17].

The difference in disease awareness was particularly pronounced. Only 2.74% of respondents had heard of coxiellosis or Q fever, compared with 43.15% who knew of brucellosis. These findings suggest that coxiellosis receives considerably less recognition among participating farmers, despite previous serological and molecular evidence demonstrating a herd-level *C. burnetii* prevalence of 74.35% in northeastern Thailand [12] and *C. burnetii* seropositivity in goats in central and western Thailand [31]. Although herd-level infection prevalence and self-reported farmer awareness are different outcomes and are not directly comparable, the discrepancy between documented pathogen circulation and farmers' awareness highlights the need to strengthen communication regarding coxiellosis in goat production systems.

The greater representation of brucellosis-specific measures in the questionnaire should also be considered when interpreting preventive practice scores. These scores predominantly reflect compliance with brucellosis-oriented control measures and general farm biosecurity practices rather than comprehensive coxiellosis-specific prevention. Nevertheless, several assessed behaviors are relevant to both infections, particularly hygienic handling and disposal of reproductive materials, appropriate management of kidding areas, and use of personal protective equipment during parturition.

Preventing coxiellosis also requires attention to environmental contamination, aerosol exposure, manure and bedding management, and potential animal-associated sources of infection. Integrating coxiellosis awareness and relevant preventive recommendations into existing veterinary extension and small-ruminant health programs may therefore strengthen prevention of both diseases [7].

Sociodemographic characteristics and reported disease history

Farmers were nearly equally distributed by sex, with a median age of 53 years and 4 years of farming experience. These characteristics provide contextual information about the surveyed farming population and the production environment in which preventive practices were evaluated.

A substantial proportion of farmers reported reproductive and clinical disorders in their herds, particularly weak-born kids, abortion, arthritis, sterility, and orchitis. Several of these manifestations are compatible with the recognized clinical presentations of brucellosis and coxiellosis in small ruminants, including reproductive failure, stillbirth, weak offspring, and infertility [32–34]. However, other infectious, nutritional, toxic, or management-related conditions may cause similar manifestations. Consequently, the reported clinical histories cannot be attributed specifically to either pathogen.

Previous investigations have documented *C. burnetii* prevalence estimates of approximately 10%–50% in certain endemic settings [35–37]. These epidemiological observations provide context for considering reproductive health problems in goat herds, although the present study did not evaluate the relationship between reported clinical histories and infection status.

A history of illness in a family member was reported by 21.92% of respondents. These reports provide information about perceived household illness but do not establish an association with livestock exposure or zoonotic infection.

Participants frequently reported potential animal reservoirs and vectors within or around participating farms, including dogs (69.12%), rats (68.61%), birds (59.12%), cats (34.31%), squirrels (28.47%), and ticks (24.09%). Both *Brucella* spp. and *C. burnetii* have been associated with multiple domestic and wild animal hosts, while *C. burnetii* has a particularly broad ecological distribution involving mammals, birds, and arthropods, including ticks [7, 33, 38].

The frequent presence of these animals in farming environments underscores the importance of integrated farm hygiene, environmental management, and appropriate precautions for animal contact. However, their presence alone does not demonstrate pathogen carriage, reservoir competence, or involvement in transmission within the surveyed herds.

Demographic and herd-related factors associated with KAP

Educational attainment and disease-related knowledge: Higher educational attainment was positively associated with knowledge scores in both the multiple regression and path analyses. In the regression model, farmers with a bachelor's degree or higher showed greater knowledge, whereas graduate education was

positively associated with knowledge in the path model. These findings are consistent with previous KAP investigations reporting positive associations between formal education and disease awareness among livestock farmers [39–41].

Educational attainment may relate to differences in access to veterinary information, understanding of disease prevention recommendations, and engagement with formal information channels. However, these potential explanations were not directly evaluated in the present study.

The association between education and knowledge remained statistically significant after accounting for farm-level clustering and questionnaire administration mode. In contrast, associations between educational attainment and attitudes or preventive practices were attenuated after adjustment for administration mode. This finding is relevant because online respondents were substantially more likely to hold graduate degrees than participants completing paper-based questionnaires. Accordingly, educational attainment and questionnaire administration mode were closely related within the sample.

A reported history of illness in a family member was negatively associated with knowledge scores. Previous studies have discussed the potential influence of disease attribution and perceptions of illness on zoonotic disease awareness [42, 43]. However, the present data do not establish why respondents reporting household illness had lower knowledge scores. The observed association therefore warrants further investigation rather than interpretation as evidence of a specific behavioral or epidemiological mechanism.

Reported herd health problems and preventive practices: Reported histories of arthritis and abortion were associated with preventive practice scores, although the directions of these associations differed. Arthritis was positively associated with practices in both the multiple regression and path analyses, with coefficients of 4.00 and 2.82, respectively. Conversely, abortion was negatively associated with preventive practices, with a path coefficient of −3.13 and a standardized coefficient of −0.25, compared with 0.23 for arthritis.

The positive association between reported arthritis and preventive practices may be compatible with greater attention to disease management among farmers who have previously observed clinical problems in their herds. However, the negative association between abortion and preventive practices indicates that the relationship between reported disease history and preventive behavior is not uniform across clinical manifestations.

Differences in disease recognition, farm management, exposure history, and reporting behavior may contribute to these contrasting associations. Farmers who monitor their animals more closely may also be more likely to identify clinical abnormalities and report preventive practices. The findings therefore establish statistical relationships between reported herd health histories and preventive practice scores without identifying the underlying mechanisms.

Farming experience of ≥ 5 years was positively associated with preventive practices in the multiple regression model but was not statistically significant in the path model. The models included different explanatory variables and adjustment structures. In particular, the path model additionally incorporated knowledge and attitudes as predictors of preventive practices, whereas the regression model included educational attainment and other reported herd and household characteristics directly in the practice equation.

The reduction in the farming experience coefficient from 2.57 in the regression model to 1.26 in the path model indicates that the estimated association depended on the variables included in the model. These findings should therefore be interpreted according to the respective model specifications rather than as evidence that farming experience independently determines preventive behavior.

Relationships among KAP domains: Knowledge and attitudes were moderately and positively correlated, whereas knowledge and practices showed a weaker positive correlation. Attitudes and practices were also positively correlated. These findings align with the conventional sequential KAP framework, which proposes that knowledge is associated with attitudes and that both domains relate to preventive behavior [15, 44]. Similar positive knowledge–attitude associations have been reported in previous studies involving livestock farmers [40, 45, 46].

Despite these positive associations, the overall preventive practice score remained considerably lower than the attitude score. This discrepancy aligns with previous public and veterinary health research showing that knowledge and favorable attitudes do not consistently translate into recommended behaviors [47, 48].

The variation across preventive practice domains provides additional context. Farm certification (30.82%) and animal movement (31.10%) had the lowest proportions of recommended responses, whereas farm management (72.83%) and personal protection (67.38%) had the highest.

Farm certification and movement-related measures may require access to veterinary testing, official

certification procedures, transportation, and financial resources. By comparison, farmers can implement several routine farm management and personal protection practices directly. The observed differences are therefore compatible with the possibility that access to external services and resources influences preventive behavior, although the study did not directly quantify these factors.

These findings suggest that disease prevention programs should consider both farmers' knowledge and attitudes and the practical requirements associated with implementing recommended measures. Educational activities may be more useful when accompanied by accessible veterinary services and feasible farm-level biosecurity recommendations.

Direct and indirect associations among KAP domains: Path analysis identified positive direct associations of knowledge and attitudes with preventive practices. Knowledge was also positively associated with attitudes, and the indirect knowledge–practice association through attitudes was statistically significant.

The indirect association accounted for approximately 39% of the total estimated knowledge–practice association, indicating that the hypothesized pathway through attitudes represented a substantial component of the statistical relationship among these domains. This pattern was consistent with the positive pairwise correlations and the sequential structure specified in the conventional KAP framework.

However, the direct knowledge–practice association was weaker than the attitude–practice association. Furthermore, although the direct knowledge–practice coefficient remained statistically significant after adjusting for farm-level clustering, it was attenuated and no longer significant after adjusting for questionnaire administration mode. In contrast, the attitude–practice association remained statistically significant under both sensitivity analyses.

These findings indicate that the attitude–practice association was more consistent across the examined model specifications than the direct knowledge–practice association. They also demonstrate the importance of accounting for questionnaire administration characteristics when interpreting associations among KAP domains.

Previous research suggests that disease prevention initiatives may benefit from combining knowledge enhancement with approaches that address attitudes, perceptions, and practical behavioral requirements [43, 48, 49]. These findings align with this integrated approach, although evaluating the effectiveness of such interventions requires appropriately designed prospective studies.

The path model explained approximately 16%–28% of the variation across the three KAP domains, including 27.50% of the variation in preventive practices. Thus, substantial variation in reported preventive behavior was not explained by the measured variables.

Previous behavioral research has identified several additional factors potentially relevant to disease prevention, including veterinary service availability, affordability of diagnostic testing, agricultural extension support, financial consequences of disease control, market incentives, perceived disease risk, and social-network influences [49, 50]. These factors provide directions for further investigation into the practical determinants of biosecurity adoption among smallholder goat farmers.

Implications for disease control and public health

The findings inform the design of veterinary extension and zoonotic disease prevention programs targeting meat goat production systems in northeastern Thailand. The observed associations among KAP support the relevance of educational approaches that address both disease-related understanding and farmers' perceptions of prevention and control.

Educational materials should emphasize transmission pathways, occupational exposure during kidding, hygienic handling and disposal of reproductive materials, appropriate use of personal protective equipment, animal movement management, and the importance of laboratory-based disease surveillance. Information should be presented in accessible formats appropriate for farmers with different educational backgrounds.

Community-based veterinary extension, participatory farmer training, and established local communication networks may provide practical mechanisms for delivering disease prevention information. Previous studies have recommended tailored training and community-level communication to address knowledge–practice gaps in livestock production settings [21, 41, 45, 51].

However, improving awareness alone may not be sufficient to increase implementation of preventive practices. The relatively low scores for farm certification and animal movement indicate the importance of considering access to diagnostic testing, veterinary services, certification procedures, and affordable biosecurity resources. Integrating educational initiatives with practical veterinary support may help address these

implementation requirements.

The particularly low awareness of coxiellosis highlights the need to incorporate Q fever into routine farmer education and veterinary extension activities. Existing brucellosis prevention programs may provide an organizational foundation for communicating shared zoonotic risks and introducing additional coxiellosis-specific recommendations.

An integrated One Health approach involving veterinary, public health, agricultural, and community stakeholders may further support coordinated management of zoonotic risks at the animal–human–environment interface. Particular attention should be directed toward reproductive waste management, environmental hygiene, occupational protection, and communication between animal and human health services.

The findings also provide a basis for future investigations combining farmer-reported KAP assessments with serological surveillance, molecular pathogen detection, environmental sampling, and longitudinal evaluation of preventive behaviors. Such investigations could help establish how disease awareness, reported practices, and verified pathogen exposure are related within smallholder meat goat production systems.

Limitations

Several limitations should be considered when interpreting the findings. First, participants were recruited voluntarily from an established meat goat farmers' network rather than through probability-based sampling. This approach may have introduced selection bias because network members could have greater access to veterinary services and animal health information than nonmembers. Furthermore, the achieved sample size (n = 146) was substantially smaller than the calculated target of 329. Recruitment was restricted to the one-year period specified in the approved study protocol, during which no additional farmers volunteered. The achieved sample size corresponded to an estimated precision of approximately ±7.79 percentage points for a population proportion (95% confidence level, expected proportion of 57.7%, and finite population correction for 2,634 farmers; ±8.01 percentage points without correction). Consequently, nonsignificant associations should not be interpreted as evidence of no association. Recruitment was also geographically uneven, with district-level participation ranging from one to 31 farmers. Because the study was confined to two provinces and participants belonged to a single farmers' network, the generalizability of the findings to other goat farming populations in Thailand is limited.

Second, the cross-sectional study design did not permit determination of temporal relationships or causal associations among KAP domains. Although path analysis identified significant direct and indirect statistical associations, the specified pathways represent hypothesized relationships rather than demonstrated causal mechanisms. The path model satisfied the prespecified fit criteria ($\chi^2 = 18.10$, df = 16, p = 0.318; CFI = 0.980; TLI = 0.963; RMSEA = 0.030; SRMR = 0.031), and no modification index exceeded 6. Nevertheless, satisfactory model fit indicates compatibility between the specified model and the observed covariance structure, rather than confirming the assumed pathway directions. The modest adjusted R^2 values of the regression models (0.153–0.201) and path model (0.139–0.249) further indicate that substantial variation in KAP scores remained unexplained, suggesting possible influence from unmeasured behavioral, socioeconomic, and farm management factors.

Third, the study relied on self-reported information, which may have introduced recall, reporting, and social desirability biases. Preventive practices were not independently verified through direct farm observations, and respondents may have overreported recommended behaviors. Similarly, histories of reproductive disorders in goats and illness among family members were based on farmers' reports. Because no laboratory testing of animals or humans was performed, these clinical histories could not be attributed to *Brucella* spp. or *C. burnetii*. Accordingly, the reported clinical manifestations should be interpreted as nonspecific health histories rather than evidence of confirmed infection.

Fourth, the questionnaire underwent incomplete psychometric validation. No formal content-validity assessment involving independent external experts or separate pilot evaluation of the expanded questionnaire was conducted before data collection. Internal consistency was assessed using the study sample rather than an independent validation sample. Cronbach's alpha was 0.60 for the attitude domain, below the conventional threshold of 0.70, indicating limited internal consistency. Furthermore, the three-point attitude response scale, selected to improve comprehensibility among farmers with limited formal education, produced pronounced ceiling effects and restricted discrimination among respondents. The attitude findings therefore require cautious interpretation. The composite practice score also simplified heterogeneous preventive behaviors into equally

weighted binary responses, potentially overlooking differences in their practical importance and context-dependent appropriateness. Although four items considered insufficiently representative of preventive behavior were excluded from scoring, the remaining items still encompassed diverse farm management activities.

Fifth, the questionnaire emphasized brucellosis-related preventive measures because Thailand's established surveillance and certification framework primarily addresses brucellosis rather than coxiellosis. Consequently, the composite practice score predominantly reflected brucellosis-oriented disease prevention and general farm biosecurity rather than a comprehensive assessment of coxiellosis-specific practices. This imbalance should be considered when comparing disease awareness with reported preventive behaviors.

Sixth, questionnaires were administered using three methods, with interviewer administration accounting for 100 of 146 responses. Knowledge and practice scores differed significantly among administration methods, and the groups also differed substantially in age and educational attainment. After adjustment for selected covariates, online administration remained associated with higher knowledge scores and, in the path model, higher practice scores, although the corresponding association with practices was not significant in the multiple regression model. Because participants selected their preferred administration method, differences attributable to respondent characteristics could not be distinguished reliably from potential administration mode effects. Interviewer-related influences and social desirability bias may also have affected responses.

Finally, the independence of observations was not fully assured because eight farms contributed more than one respondent, accounting for 17 of the 146 records. Farm-clustered robust standard errors were therefore used in sensitivity analyses. After accounting for clustering, the associations between reported orchitis and attitudes in both the regression and path models, and between residence in Chaiyaphum Province and preventive practices in the regression model, no longer met the significance threshold. Conversely, graduate education became significantly associated with attitudes in the path model. Associations among the KAP domains retained their directions and statistical significance after adjustment for farm-level clustering. However, potential clustering by district and within farmers' networks, along with residual confounding from unmeasured factors, could still affect the precision and interpretation of the estimates. Moreover, the direct knowledge–practice association was no longer statistically significant after adjustment for questionnaire administration mode, indicating sensitivity to the analytical specification.

Future investigations should employ larger, probability-based samples with more balanced geographical representation, formal questionnaire validation, and improved measurement of attitudes and preventive behaviors. Longitudinal designs incorporating direct farm observations, laboratory confirmation of infection, and assessments of veterinary service accessibility would help clarify the relationships among KAP, biosecurity implementation, and disease occurrence.

CONCLUSION

This study identified a substantial knowledge–practice gap regarding brucellosis and coxiellosis among meat goat farmers in northeastern Thailand. Although farmers demonstrated moderately favorable knowledge (66.54%) and attitudes (81.60%), the overall preventive practice score remained comparatively low (51.07%). Awareness of coxiellosis was particularly limited (2.74%) compared with brucellosis (43.15%). Farm certification and animal movement were the weakest preventive practice domains. Path analysis identified positive associations among KAP domains, including a significant indirect knowledge–practice association through attitudes. However, the direct knowledge–practice association was attenuated after adjustment for questionnaire administration mode.

The findings highlight the importance of integrating disease-specific education with accessible veterinary services and practical biosecurity support. Farmer education should address both brucellosis and coxiellosis, emphasizing disease transmission, reproductive waste management, personal protection, herd testing, and safe animal movement. Existing brucellosis control and extension programs could provide a foundation for improving awareness of coxiellosis. Particular attention should be given to reducing barriers to farm certification, diagnostic testing, and implementation of recommended preventive measures.

The study jointly assessed KAP concerning two important reproductive zoonoses in a smallholder meat goat production system. Integrating descriptive analyses, multiple regression, and path analysis provided insight into direct and indirect statistical associations among KAP domains. Farm level clustering and questionnaire administration mode sensitivity analyses further supported a more comprehensive assessment of the consistency

of the observed associations.

Future research should include larger, probability-based samples and longitudinal investigations to clarify the relationships among KAP, preventive behaviors, and disease occurrence. Improved questionnaire validation, direct observation of farm biosecurity practices, and laboratory-based surveillance would strengthen the evidence. Intervention studies should evaluate whether integrated farmer education, accessible veterinary services, and targeted biosecurity support improve preventive practices and reduce zoonotic disease risks.

The findings demonstrate that favorable attitudes and moderate disease-related knowledge do not necessarily translate into consistent preventive practices among meat goat farmers. The particularly low awareness of coxiellosis and inadequate implementation of farm certification and animal movement measures indicate important priorities for veterinary extension and disease prevention. An integrated One Health approach that combines farmer education, practical biosecurity measures, accessible veterinary services, and coordinated zoonotic disease surveillance may more effectively prevent brucellosis and coxiellosis in smallholder goat production systems.

DATA AVAILABILITY

The anonymized participant-level dataset, including farm identifiers and questionnaire administration modes; the questionnaire codebook specifying the scoring direction of each item; the R analysis script; and the *lavaan* model syntax are available in Supplementary Tables S1, S2, and S5 and Supplementary Files S3 and S4 and have been deposited in the Zenodo repository at https://doi.org/10.5281/zenodo.22474147.

Supplementary Table S1. Questionnaire items comprising 14 knowledge items, 15 attitude items, and 44 practice items, together with four excluded practice items.

Supplementary Table S2. Coding scheme, scoring directions for all questionnaire items, including reverse-coded items, procedures for handling missing data, and reference categories for categorical predictors.

Supplementary File S3. Anonymized participant-level dataset containing farm identifiers, questionnaire administration modes, and derived KAP domain scores.

Supplementary File S4. R analysis script and *lavaan* model syntax used for statistical analyses.

Supplementary Table S5. Additional statistical results comprising the following sections:

- **S5.1:** Standardized path coefficients.
- **S5.2:** Conventional and farm-clustered robust standard errors for all regression and path coefficients.
- **S5.3:** KAP domain scores by questionnaire administration mode and complete estimates from regression and path models adjusted for administration mode.
- **S5.4:** Modification indices for the path model.

GENERATIVE AI DECLARATION

The authors declare that generative artificial intelligence (AI) tools were used solely to improve language, grammar, and readability during manuscript preparation. All scientific content, data analysis, interpretation of results, and conclusions were developed and verified by the authors. The authors take full responsibility for the accuracy, integrity, and originality of the work presented, and no AI tool was listed as an author.

AUTHORS' CONTRIBUTIONS

SR, PP, NC, SL, PS, SS, and VP: Conceptualization and study design. SR, PP, and NC: Investigation and data collection. SR, SL, PS, SS, and VP: Data curation and validation. SR, SL, and VP: Data visualization. SR, SL, SS, and VP: Formal analysis. SR and VP: Writing – original draft preparation. All authors contributed to reviewing and editing the manuscript. All authors have read, reviewed, and approved the final manuscript.

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COMPETING INTERESTS

The authors declare that they have no competing interests.

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