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Research article

Consumer knowledge, attitudes, and food safety practices in livestock-based food systems: Evidence from buffalo meat consumption in Northern Thailand

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Abstract: Although buffalo meat is an important component of livestock-based diets in tropical smallholder systems, there has been limited empirical research on consumer food safety-related behaviors associated with its consumption. Thus, we examined the behavioral determinants of buffalo meat consumer safety based on the Knowledge–Attitudes–Practices (KAP) framework. Partial least squares structural equation modeling (PLS-SEM) was applied to survey data from 250 buffalo meat consumers in Northern Thailand to assess the direct, indirect, and predictive relationships among the KAP constructs. There were significant correlations across all constructs, the strongest of which was between attitudes and practices ($r = 0.52$, $p < 0.001$). Knowledge had a positive effect on attitudes ($\beta = 0.471$, $p < 0.001$) and influenced practices directly ($\beta = 0.312$, $p < 0.001$) and indirectly through attitudes ($\beta = 0.235$, $p < 0.001$). Attitudes had the strongest direct effect on practices ($\beta = 0.499$, $p < 0.001$). The model demonstrated moderate explanatory power and high predictive relevance, and all Q^2 values were greater than zero. These findings indicate that the mechanisms underlying perception and attitude are the key predictors of safe buffalo meat consumption. On the other hand, demographic factors account for only a small portion of behavioral variance. This study is novel because it represents the first empirical investigation of buffalo meat consumption behavior in a tropical livestock context. The results can be used to design consumer-focused communication, education, and market interventions to improve food safety outcomes within buffalo meat supply chains.

Keywords: buffalo meat; consumer behavior; food safety; Knowledge–Attitudes–Practices (KAP); meat consumption

1. Introduction

The Greater Mekong Subregion in Southeast Asia is an important food provider and source of rural livelihoods, including buffalo production. In Northern Thailand, buffalo consumption is culturally rooted and economically significant. Buffalo production in this region is mostly based on smallholder, free-grazing, and semi-intensive systems that supply meat to local markets and contribute to household food security and income [1,2]. Beyond its socio-economic relevance, buffalo meat has desirable nutritional characteristics, including low fat and cholesterol levels and a healthier fatty acid profile compared with beef, so it has become an increasingly attractive animal-source food [3,4].

Despite these benefits, there are several food safety risks associated with buffalo meat produced by tropical smallholder systems along the farm-to-fork continuum. For example, informal slaughtering, inconsistent sanitary oversight, inadequate cold-chain control, and the cultural practice of eating raw or insufficiently cooked buffalo meat can increase the risk of contamination with pathogens such as *Brucella* spp., *Salmonella* spp., *Taenia* spp., and *Escherichia coli*. These challenges have been reported in the livestock systems of several low- and middle-income countries (LMICs) due to inadequate and inconsistent regulation and consumer practices [5,6]. Therefore, it is essential to understand how consumers perceive and respond to these risks so that safety within buffalo meat supply chains can be improved.

Researchers studying meat consumption in Southeast Asia have mostly focused on the socio-economic, sensory, and/or cultural determinants of consumer preferences; for example, buffalo meat in Bangladesh and ruminant meat systems in Laos [1,5]. In the livestock sector, food safety researchers have applied descriptive Knowledge–Attitudes–Practices (KAP) surveys to food handlers or occupational groups [6,7]. However, they have rarely examined the structural relationships between knowledge, attitudes, and safety practices. Moreover, the available studies have not considered consumers of buffalo meat in Northern Thailand, who are exposed to distinctive risks linked to the popularity of consuming dishes with raw buffalo meat and the traditional slaughtering systems in the region. Consequently, there is a poor understanding of the processes involved in translating knowledge into safe (or unsafe) buffalo meat–handling practices.

Beyond individual behavior, consumer knowledge, attitudes, and practices are also directly connected to the upstream aspects of buffalo production systems. Over time, shifts in safety knowledge and trust within tropical value chains dominated by smallholder systems have increased the demand for certified farms, hygienic slaughtering, and traceable meat. These trends, in turn, pressure producers to improve their practices [8]. Rising consumer concern has been shown to improve animal handling, welfare, and cold-chain management in similar livestock systems in LMICs [9].

The KAP framework offers a practical behavioral model to assess the food safety of livestock products. It posits that an accurate understanding of the hazards related to livestock origins shape risk-related attitudes, which then translate into practices. This chain of action parallels well-established behavioral theories, including the Theory of Planned Behavior, and emphasises that attitudes play an intermediary role between knowledge and behavior [10]. However, the KAP framework has not been widely applied in the context of tropical livestock products, despite its relevance to general food safety, including buffalo meat. Moreover, these pathways have not been empirically validated through structural modeling, even though it is intuitively clear that consumer behavior, rather than demographic factors, is likely to be the most critical element in conventional meat value chains.

The exploration of these relationships require more advanced analytical techniques, especially given that food safety data are ordinal and non-normally distributed and that explanatory and predictive performance must be considered. Partial least squares structural equation modeling (PLS-SEM) is well suited for this endeavour because it accommodates complex models, smaller samples, and data that do not follow a normal distribution. Moreover, the PLSpredict method enables out-of-sample prediction to assess the predictive ability of the model, although this approach has rarely been used in research on the behavior of livestock consumers.

To address the abovementioned gaps, we evaluated the predictors of safe buffalo meat consumption in Northern Thailand based on a livestock-based KAP framework. Specifically, PLS-SEM was used to analyze the direct and indirect relationships between knowledge, attitudes, and practices related to safe buffalo meat consumption. Four hypotheses were tested: (H1) Knowledge has a positive effect on attitudes; (H2) knowledge has a positive effect on practices; (H3) attitudes have a positive effect on practices; and (H4) attitudes mediate the relationship between knowledge and practices. The findings from this study should clarify consumer behavior in response to livestock-related food safety risks and provide guidance for developing targeted interventions to improve the safety of buffalo meat consumption in Northern Thailand and other tropical smallholder contexts.

2. Theoretical background and research hypotheses

2.1. Buffalo meat safety in tropical livestock production systems

Buffalo meat is an important part of animal-source food systems in several tropical areas, such as Northern Thailand. It is mostly employed by the smallholder farmers who adopt extensive and semi-intensive management. The buffaloes in such systems frequently are kept under unpredictable hygienic conditions. Additionally, slaughtering can be conducted formally and informally, and sanitation can be apathetic [11]. Buffalo meat is generally sold in wet markets where cold-chain preservation cannot be guaranteed after slaughter. All these structural features, along with the cultural tendency toward uncooked or undercooked foods such as *larb dib*, contribute to the heightened risk of contact with pathogens such as *Toxoplasma gondii*, *Brucella* spp., *Taenia* spp., and *Salmonella* spp. [12–14]. Consumer awareness and decision-making have a vital role to play in this tropical livestock setup in eliminating meat safety hazards.

Although certification schemes such as Good Farm Management, Good Agricultural Practices, and the Livestock OK programme aim to improve hygiene and traceability, they are not applied consistently. Thus, the hygienic conditions under which buffalo meat is slaughtered, the cold-chain control, and consumer behavior have an upstream effect on the safety of buffalo meat in Northern Thailand.

According to the livestock-based KAP model, buffalo meat safety knowledge should be able to affect risk perception and attitudes of the consumers, which determine the safety practices of the consumers. In tropical smallholder systems, where hazards stem from production, slaughtering, and raw meat consumption behaviors, knowledge, attitudes, and practices likely interact directly and indirectly, leading to the four hypotheses tested in this study.

2.2. Knowledge and attitudes

In tropical buffalo systems, perceived risks are shaped by consumer awareness of livestock-specific hazards such as carcass contamination, poor cold-chain management, and zoonotic risks associated with raw buffalo meat. When consumers are aware of these issues, they can form judgements about safety hazards and develop attitudes toward certified sources of buffalo meat that involve sanitary handling during and after slaughter. Unlike general food safety settings, buffalo meat value chains have distinctive upstream risks linked to smallholder production and informal slaughtering, so livestock-related knowledge is particularly important in shaping safety attitudes.

H1. Knowledge of buffalo meat safety positively influences consumers' attitudes toward safe handling and consumption of buffalo meat.

2.3. Knowledge and practices

Knowledge can also directly influence practices. When consumers fully understand the dangers of informal slaughtering, eating raw meat, and exposure to poor conditions during transport, they are more inclined to take preventive measures to reduce associated risks. These practices include using certified buffalo meat, maintaining appropriate storage temperatures, and avoiding the consumption of raw meat.

H2. Knowledge of buffalo meat safety positively influences consumers' safety-related practices throughout the purchasing, handling, and consumption process.

2.4. Attitudes and practices

Attitudes also shape how consumers translate their knowledge into action. Positive intentions regarding safety, that is, consumers value certified meat sources, have confidence in hygienic slaughter systems, and hold unfavourable views of raw meat consumption, are linked to safer behavior during purchasing and consumption.

H3. Attitudes toward buffalo meat safety positively influence consumers' safety practices related to buffalo meat.

2.5. Attitudes as a mediator

Within the KAP framework, attitudes commonly mediate the transformation of knowledge into behavior. Even when consumers possess knowledge of the safety risks related to buffalo meat, behavioral change depends on whether that knowledge translates into meaningful risk perceptions and beliefs. This mediation is especially relevant in tropical livestock systems, where consumers continue to consume raw meat despite well-known hazards. Therefore, attitudes serve as the pathway through which knowledge affects safety practices.

H4. Attitudes toward buffalo meat safety mediate the relationship between knowledge and safety practices related to buffalo meat.

3. Materials and methods

3.1. Study design and sampling procedure

In this cross-sectional analytical study, we used the KAP framework to identify the factors that influence buffalo meat consumption. The research took place in three major buffalo-producing provinces in Northern Thailand (Phayao, Chiang Rai, and Phrae), which represent diverse production systems, cultural consumption patterns, and emerging markets for buffalo meat products. While buffalo meat has high economic importance in these provinces, empirical consumer-level data are limited, underscoring the need for a systematic behavioral assessment using a KAP-based model.

A PLS-SEM power analysis was performed using G*Power 3.1 to ensure the structural model had adequate statistical power. The maximum number of predictors for an endogenous construct was two (knowledge and attitudes predicting practices). With a medium effect size ($f^2 = 0.15$), $\alpha = 0.05$, and power = 0.95, a minimum of 119 observations would be required. Thus, the sample of 250 respondents provided sufficient statistical power for stable estimation and reliable inference of the path coefficients.

3.2. Development of the data collection instrument

A questionnaire was used to gather data with three main sections. Demographic information such as sex, age, education, income, and household size was captured in the first section. In the second section, we analyzed the attitudes toward buffalo meat consumption, such as preferred meat type and cut, preferred dishes, frequency of consumption, and frequency of purchase. These behaviors are specific to Northern Thailand where buffalo meat is consumed but not extensively studied. In the third section, we assessed knowledge, attitudes, and practices. There were 15 items in each construct (45 items overall), and these are listed in Table S1. Knowledge items were scored as correct (1) or incorrect (0), while attitude and practices were scored on the Likert scale, which is a 5-point scale. Dichotomous scoring was used for knowledge items because they were intended to measure factual knowledge that was objective and factual, related to buffalo meat safety, foodborne pathogens, and hygienic handling practices. Attitudes and practices are subjective perceptions and self-reported behaviors and are more suitable to be measured by Likert-type scales. The composite scores of knowledges, attitudes, and practices were standardised to a 0–100 scale for easy comparison between constructs. In the case of the knowledge construct, responses that were correct received a score of 1, while those that were incorrect received a score of 0, resulting in a total possible score ranging from 0 to 15. The total score was then scaled to a standard 0–100 percentage score based on the following formula: (Observed score/Maximum possible score) × 100. For the attitudes and practices constructs, responses to the 15 Likert-scale items (1–5 points) were summed and similarly transformed into standardized 0–100 scores using the observed score relative to the maximum possible score. This standardization enabled us to compare the constructs directly. Internal consistency was acceptable to high, with Cronbach's α of 0.82 for knowledge, 0.91 for attitudes, and 0.89 for practices.

3.3. Data collection procedure

The data were collected via face-to-face interviews conducted by trained enumerators. This approach was necessary to ensure accuracy and to reach consumers living in semi-urban and rural areas where buffalo meat consumption is prevalent. This method was particularly appropriate given the diverse backgrounds of the respondents and limited access to reliable online sampling frames in the study region. Prior to each interview, the respondent provided written informed consent. Anonymity and confidentiality were strictly maintained.

3.4. Statistical analysis

SPSS Statistics version 23 (IBM Corp. Armonk, NY, USA) and RStudio 2025.09.2 were used for all statistical analyzes, with a significance threshold of $p < 0.05$. Demographic characteristics; buffalo meat consumption behavior; and knowledge, attitude, and practice scores were summarised using descriptive statistics. According to the Shapiro–Wilk test, the knowledge, attitude, and practice scores were not normally distributed ($p < 0.05$). Thus, they were analyzed with non-parametric tests: The Mann–Whitney U test for comparisons between two groups, and the Kruskal–Wallis test for comparisons among three or more groups. The Dunn–Bonferroni adjustment was used for post hoc pairwise comparisons. Correlations between the knowledge, attitude, and practice scores were assessed using Spearman's rho due to the ordinal nature and non-normal distribution of the data.

Given our aim of this study to analyze the predictive and causal relationships within the KAP framework, PLS-SEM was conducted using the cSEM package in RStudio 2025.09.2. This approach was appropriate due to the nature of the model: Behavioral data that do not follow a normal distribution, exploratory constructs, and theoretical extension are typical in consumer research using the KAP framework [15]. Indicator loadings, composite reliability, average variance extracted (AVE), the heterotrait–monotrait ratio (HTMT), and variance inflation factors were used to evaluate the measurement model. Bootstrapping with 3,000 resamples was employed to assess the structural model to obtain the path coefficients, confidence intervals, effect sizes (f^2), predictive relevance (Q^2), and explained variance (R^2).

The PLSpredict procedure in the cSEM package was applied to assess the model's predictive performance. The analysis generated case-level predictions for all endogenous constructs and compared the PLS-SEM model with a linear benchmark model. The root mean square error (RMSE) and mean absolute error (MAE) were used to evaluate the predictive accuracy of the manifest indicators and construct scores. Q^2_predict was used to assess predictive relevance. Values greater than zero indicated meaningful out-of-sample predictive power. Additionally, the predictive superiority of the model was evaluated by comparing PLS-based prediction errors with those of the linear model, following the recommendations of Shmueli et al. [16].

3.5. *Ethics approval of research*

This study received ethical approval from the University of Phayao Human Research Ethics Committee (HREC-UP-HSST 1.2/167/68).

4. Results and discussion

4.1. Descriptive characteristics of the respondents and buffalo meat consumption behaviors

Demographic data for the 250 buffalo meat consumers who participated in the study are shown in Table 1. Most respondents were female (65.2%) and 20–30 years old (34.0%). In terms of education, respondents were distributed across educational levels, with bachelor's degree holders representing the largest proportion (34.8%). The annual incomes of most respondents (33.2%) ranged between 10,000 and 50,000 baht, and households of 4–5 members were the largest group (45.6%). The respondents were demographically heterogeneous, which is a representative characteristic of the population of meat eaters, in which the socio-economic, cultural, and household factors influence the preferences and buying decisions of the population [17]. The overall demographic profile broadly aligned with the general picture of food consumption in other livestock-based food systems in Southeast Asia, reflecting the food consumption patterns that are largely driven by considerable diversity in household structures and socio-economic status [2].

Table 1. Demographic characteristics of the respondents (n = 250).

Variable	Category	n	%	χ^2	p-value
Sex	Female	163	65.2	23.104	<0.001
	Male	87	34.8		
Age	<20 years	48	19.2	67.232	<0.001
	20–30 years	85	34.0		
	31–40 years	29	11.6		
	41–50 years	36	14.4		
	51–60 years	36	14.4		
	>60 years	16	6.4		
Education	Primary school	28	11.2	29.648	<0.001
	Secondary school	70	28.0		
	Vocational/higher vocational	65	26.0		
	Bachelor's degree	87	34.8		
Income	<10,000 baht/year	43	17.2	42.480	<0.001
	10,000–50,000 baht/year	83	33.2		
	50,000–100,000 baht/year	61	24.4		
	100,000–150,000 baht/year	22	8.8		
	>150,000 baht/year	41	16.4		
Number of household members	1–2	21	8.4	71.184	<0.001
	2–3	61	24.4		
	4–5	114	45.6		
	>5	54	21.6		

As shown in Table 2, there was notable heterogeneity among the respondents in how they consume buffalo meat. Almost half of the respondents consumed cooked and raw buffalo meat. Note that the consumption of raw or undercooked meat is a culturally rooted practice across Asian populations, particularly in rural and traditional communities [18]. The most preferred cooking method was grilling (34.4%), a finding consistent with the fact that sensory expectations, including flavour, texture, and perceived juiciness, play a major role in consumer choices [17]. The respondents preferred the tenderloin and brisket, likely due to their tenderness and the culinary traditions associated with these cuts in regions where buffalo meat is commonly consumed [19].

Most of the respondents (63.6%) reported eating buffalo meat 1–2 times per week, indicating a regular but moderate consumption pattern. Zainalabidin et al. [20] reported modest consumption influenced by availability and price in neighbouring Southeast Asian countries. Moreover, there is often confusion between beef and buffalo meat in other countries [21]. Taken together, buffalo meat consumption behaviors are complex, and it is important to understand how knowledge and attitudes translate into actual practices within the KAP framework.

Table 2. Buffalo meat consumption behaviors of the respondents (n = 250).

Variable	Category	n	%	χ^2	p-value
Type of meat consumed	Cooked	116	46.4	99.944	<0.001
	Raw	9	3.6		
	Both	125	50.0		
Favourite meat cut	Tenderloin	75	30.0	41.800	<0.001
	Sirloin	54	21.6		
	Chuck eye	18	7.2		
	Brisket	66	26.4		
	Ribeye	37	14.8		
Favourite dish	Stew	43	17.2	15.120	<0.001
	Larb	59	23.6		
	Curry	62	24.8		
	Grilled	86	34.4		
Frequency of meat consumption	Every day	2	0.8	240.400	<0.001
	1–2 times/week	159	63.6		
	>3 times/week	18	7.2		
	Other	71	28.4		
Frequency of meat purchases	Every day	2	0.8	231.504	<0.001
	1–2 times/week	157	62.8		
	>3 times/week	20	8.0		
	Other	71	28.4		

4.2. Knowledge, attitude, and practice scores among the demographic and behavioral groups

Table 3 summarises the knowledge, attitude, and practice scores, which were relatively high. The respondents demonstrated relatively high knowledge (median = 86.67, IQR = 80.00–100.00), positive attitudes (median = 78.67, IQR = 72.00–85.33), and high levels of practices (median = 88.89, IQR = 77.78–97.78). Other researchers have reported similar KAP patterns among consumer populations in LMICs: Attitudes and habitual behaviors often exceed the level of technical food safety knowledge [22,23]. A high level of practices does not necessarily indicate that consumers have a thorough understanding of microbiological risks. The discrepancy between relatively strong behavioral practices and uneven technical food safety knowledge reflects a well-recognised knowledge–practice gap in food safety behavior [8]. Overall, Northern Thailand fits within the broader LMIC context, where familiarity with behavioral routines is strong but underlying knowledge may be uneven.

Several demographic and behavioral variables were significantly associated with the knowledge, attitude, and practice scores (Table 4). Age showed a significant relationship with attitude ($p < 0.001$) and practice ($p = 0.010$) scores, which is consistent with published evidence that age influences risk perception and food safety behavior among consumer groups [24]. Education level was associated with attitude scores ($p = 0.002$), which is in line with earlier work showing that higher levels of formal education enhance the interpretation and appreciation of food safety information [25]. Household size was strongly related to knowledge scores (p = 0.004). Similarly, Milovanova et al. [26] found that family structure affects information sharing and division of food-handling responsibilities.

Behavioral factors showed even stronger associations with knowledge, attitude, and practice scores. The frequency of meat consumption and purchases were significantly related to the knowledge, attitude, and practice scores ($p < 0.05$). These results are in line with a study suggesting that experiential learning is reinforced through repeated exposure to food preparation and purchasing, which shapes compliance with food safety practices [22]. Moreover, Grace [8] found that habitual consumption patterns shape perceived risk, knowledge, and safety behaviors related to animal-source foods. Taken together, the heterogeneity in the knowledge, attitude, and practice scores are consistent with published evidence that socio-demographic and context-specific food behaviors strongly influence food safety outcomes [23].

Table 3. Descriptive statistics of the knowledge, attitude, and practice scores (n = 250).

Variable	Mean ± standard deviation	Median (interquartile range)	Minimum–maximum
Knowledge	83.57 ± 15.29	86.67 (80.00–100.00)	20.00–100.00
Attitudes	78.57 ± 9.73	78.67 (72.00–85.33)	48.00–100.00
Practices	86.23 ± 11.49	88.89 (77.78–97.78)	57.78–100.00

*Note: The scores can be interpreted as low (<33), moderate (34–66), and high (≥67).

Table 4. Comparison of the knowledge, attitude, and practice scores across the demographic and behavioral groups (n = 250).

Variable	Knowledge score (p-value)	Attitude score (p-value)	Practice score (p-value)
Sex	0.118	0.227	0.451
Age	0.426	0.000	0.010
Education	0.628	0.002	0.067
Income	0.225	0.000	0.000
Household size	0.004	0.810	0.090
Type of meat consumed	0.155	0.243	0.730
Favourite meat part	0.423	0.079	0.648
Favourite dish	0.046	0.291	0.001
Meat consumption frequency	0.013	0.005	0.020
Meat purchase frequency	0.003	0.003	0.012

*Note: The data were analyzed with the Kruskal–Wallis test when there were three or more groups, and the Mann–Whitney U test when there were two groups. $p < 0.05$ indicates a significant difference.

4.3. Correlation analysis

Spearman's rank correlation coefficients were calculated to examine the associations between the knowledge, attitudes, and practices. All three constructs showed positive and significant correlations ($p < 0.01$ or $p < 0.001$), indicating consistent links between the cognitive, affective, and behavioral dimensions of buffalo meat consumption (Figure 1).

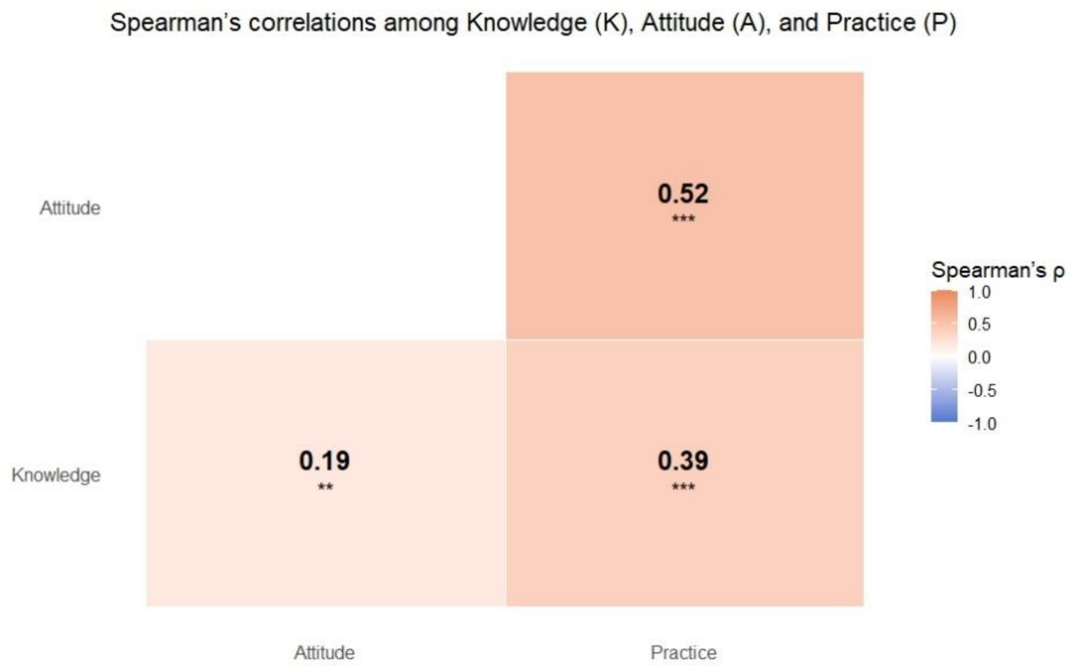

Figure 1. Spearman's rank correlation matrix shows the relationships between knowledge (K), attitudes (A), and practices (P) toward buffalo meat consumption (n = 250).

Knowledge correlated significantly with attitudes ($r = 0.19$, $p < 0.01$), suggesting that a greater awareness of buffalo meat safety and nutritional qualities corresponds with more favourable perceptions. Consistently, researchers have found that knowledge alone tends to exert a relatively modest influence on food-related attitudes [17,27]. Knowledge and practices showed a stronger correlation ($r = 0.39$, $p < 0.001$), indicating that individuals with better knowledge are more likely to adopt safer buffalo meat consumption behaviors. These patterns have been reported in studies examining food safety knowledge and meat-handling behaviors in LMICs [18,23]. Attitudes and practices showed the strongest correlation ($r = 0.52$, $p < 0.001$). Thus, affective evaluations, such as taste preferences, perceived quality, and cultural acceptance, play a central role in shaping actual consumption patterns in Northern Thailand.

Overall, these correlations provide initial empirical support for the KAP framework in tropical livestock-based food systems by confirming the expected positive relationships among the KAP constructs. The relatively strong attitudes–practices and moderate knowledge–practices correlations suggest that attitudes may serve as a key pathway through which knowledge translates into practices. Although this correlation analysis confirmed expected relationships, it could not indicate the directional effects or validate the latent constructs. Therefore, PLS-SEM was applied to assess the reliability and validity of the measurement model, followed by an evaluation of the structural relationships among the KAP constructs.

4.4. *Assessment of the measurement model*

First, the measurement model was evaluated based on indicator loadings, Cronbach's α, composite reliability, rho_A, and AVE, following the guidelines for reflective measurement models (Hair et al. 2021) (Table 5).

Table 5. Assessment of the measurement model.

Construct	Indicator	Loading	Cronbach's α	ρC	rho_A	AVE
Knowledge (K)	K1	0.729	0.7785	0.7772	0.7830	0.4089
	K4	0.690				
	K6	0.653				
	K9	0.488				
	K10	0.610				
Attitudes (A)	A4	0.724	0.8297	0.8307	0.8356	0.4521
	A5	0.672				
	A9	0.698				
	A10	0.710				
	A11	0.734				
Practices (P)	P1	0.641	0.8431	0.8420	0.8497	0.4365
	P2	0.664				
	P4	0.723				
	P5	0.709				
	P6	0.746				
	P7	0.737				
	P8	0.561				

The retained indicators of knowledge (K1, K4, K6, K9, and K10) showed loadings ranging from 0.488 to 0.729. Although K9 had a loading that was slightly below the commonly recommended 0.50 threshold [28], it was retained due to its theoretical relevance to risk awareness (an element frequently emphasised in livestock and food-safety research in LMICs) [18,23]. Although several AVE values were slightly below the recommended threshold of 0.50, the composite reliability values remained within acceptable ranges, indicating adequate internal consistency of the constructs. In addition, most indicator loadings exceeded the recommended threshold, and the retained indicators were considered theoretically relevant to the conceptual definition of each construct. Consistently, research has shown that knowledge indicators in meat and food safety assessments tend to be heterogeneous; they often reflect differences in experience, exposure, and information channels [17,29]. The indicators of attitudes (A4, A5, A9, A10, and A11) showed loadings of 0.672–0.734. These values indicate moderate yet stable coherence, which is a typical characteristic of perceptual and affective constructs [10,27]. Last, the measures of practices (0.561–0.746) were indicators of diversity in behavior consuming livestock as the meat-consuming habits depend on the cultural norms, domestic activities, and specific market structure [2].

There was strong construct reliability: Cronbach's α (0.7785–0.8431), composite reliability (0.7772–0.8420), and rho_A (0.7830–0.8497) all exceeded the recommended threshold of 0.70 [15]. The AVE values (0.4089–0.4521) were slightly below the conventional cutoff of 0.50; however, Hair et al. [30]

noted that convergent validity may be considered adequate when composite reliability exceeds 0.70, as is the case with this study. Discriminant validity was assessed using the HTMT, which was < 0.85 for all construct pairs, indicating that knowledge, attitudes, and practices are empirically distinct but conceptually related. This finding is consistent with other KAP-based studies in food safety and population health [31].

Taken together, these findings support the reliability and validity of the refined KAP constructs and thus the application of PLS-SEM. They also reflect the contextual complexity of buffalo-meat consumption in Northern Thailand, where differences in knowledge, affective evaluations, and behavioral practices are shaped by cultural norms, informal market conditions, and longstanding consumption traditions. These findings should contribute to expanding the empirical application of the KAP framework within livestock and meat safety research.

Composite reliability (ρC) > 0.70 indicates satisfactory internal consistency. Although the average variance extracted (AVE) values were slightly below 0.50, convergent validity is acceptable given that composite reliability was > 0.70 [15]. The heterotrait–monotrait ratio was < 0.85 for all construct pairs, confirming discriminant validity.

4.5. *Assessment of the structural model*

The structural model was evaluated using 3,000 bootstrap resamples to test the hypothesised causal relationships between knowledge, attitudes, and practices. As shown in Table 6, all structural paths were positive and statistically significant, supporting the proposed KAP framework.

Table 6. Assessment of the structural model.

Hypothesis and path	β	Standard error	*t*-value	*p*-value	Result
H1: K → A	0.471	0.0638	7.375	<0.001	Supported
H2: K → P	0.312	0.0849	3.672	<0.001	Supported
H3: A → P	0.499	0.0693	7.201	<0.001	Supported
H4: K → A → P (Indirect)	0.235	0.0450	5.217	<0.001	Supported
K → P (Total effect)	0.546	0.0774	7.067	<0.001	Significant
VAF	0.430				

*Note: Assessment was based on partial least squares structural equation modeling (bootstrapping = 3,000). All hypothesised paths are statistically significant ($p < 0.001$). The indirect effect indicates partial mediation (variance accounted for [VAF] = 43%). $R^2(A) = 0.47$, $R^2(P) = 0.50$ (moderate predictive power). Abbreviations: K, knowledge; A, attitudes; P, practices.

Knowledge had a direct positive effect on attitudes (β = 0.471, t = 7.375, p < 0.001), indicating that the more consumers understand buffalo meat safety and its benefits, the more favourable their evaluations become. This finding supports H1 and is consistent with behavioral theory, which suggests that cognitive inputs shape evaluative judgements [10]. In food safety contexts, Bhandari et al. [32] reported that higher levels of knowledge predict more safety-oriented attitudes. Moreover, in meat consumers, information and experience influence the formation of attitudes [33]. Consistently, Di Pasquale et al. [34] found that perceptions of production-related attributes significantly shape attitudes toward livestock products and that lack of knowledge can constrain the formation of appropriate evaluative judgements.

Knowledge also had a significant direct effect on practices (β = 0.312, t = 3.672, $p < 0.001$), supporting H2. This suggests that when consumers are more knowledgeable, they are more likely to translate that information into behaviors. Other researchers have observed this knowledge–behavior link in meat safety and livestock contexts, particularly where risk awareness and conventional handling practices intersect [18,23].

Consistent with the Spearman correlation analysis and supporting H3, the direct effect of attitudes on practice was the strongest (β = 0.722, t = 7.201, $p < 0.001$), again highlighting the central role of affective and perceptual evaluations in buffalo meat consumption. As reported in the literature, attitudes, rather than factual knowledge, are often the most powerful predictors of which meat to eat and how frequently to eat it [17,27]. In many Asian meat-eating cultures, taste, perceived quality, and traditional preparation methods strongly influence consumption decisions [2]. The strong relationship between attitudes and practices is also consistent with sensory-based findings from meat-quality studies. A case in point is the emphasis put on affective evaluations by Lunesu et al. [35], since customer perceptions of beef quality (colour, juiciness, and tenderness in particular) directly impact their scores in acceptance. Similarly, Napolitano [36] demonstrated that consumer judgments are highly influenced by the perceptions of product quality and cues that touch on production systems. Specifically, processes associated with attitude are very important in the context of acceptance and behavioral intention. Additionally, researchers who have implemented SEM in other LMIC settings have each time managed to find attitudes to be the greatest predictor of food safety behavior [29,37].

The model also showed a significant indirect relationship, with knowledge influencing practices through attitudes (β = 0.235, t = 5.217, $p < 0.001$), supporting H4. The variance accounted for (VAF) value of 0.430 indicates partial mediation, meaning that nearly half of knowledge's effect on practices operates through pathways related to attitudes. Other SEM-based studies have also shown that individuals convert knowledge into behaviors when it leads to positive affective and perceptual evaluations [29,37]. Consequently, interventions focused solely on knowledge may have limited effectiveness if they do not cultivate positive attitudes toward buffalo meat safety and consumption.

The model demonstrated moderate explanatory power, accounting for 47% of variance in attitudes and 50% in practices. These findings underscore the primary role of attitudes in buffalo meat consumption and provide new empirically based insight into consumer behavior in livestock-dependent subsistence food systems in Northern Thailand. They also highlight the need for interventions that target cognitive and affective dimensions to promote safe and sustainable buffalo meat consumption.

Figure 2 presents a graphical representation of the PLS-SEM model with the standardised path coefficients, indicator loadings, and the R^2 values for attitudes and practices. It illustrates the positive and significant pathways from knowledge to attitudes, from knowledge to practices, and from attitudes to practices. The R^2 values ($R^2 = 0.221$ for attitudes and $R^2 = 0.492$ for practices) indicate moderate explanatory power, which is consistent with previous SEM-based KAP studies that have reported similar causal patterns; in particular, the strong influence of attitudes on behavioral outcomes [32,33,37].

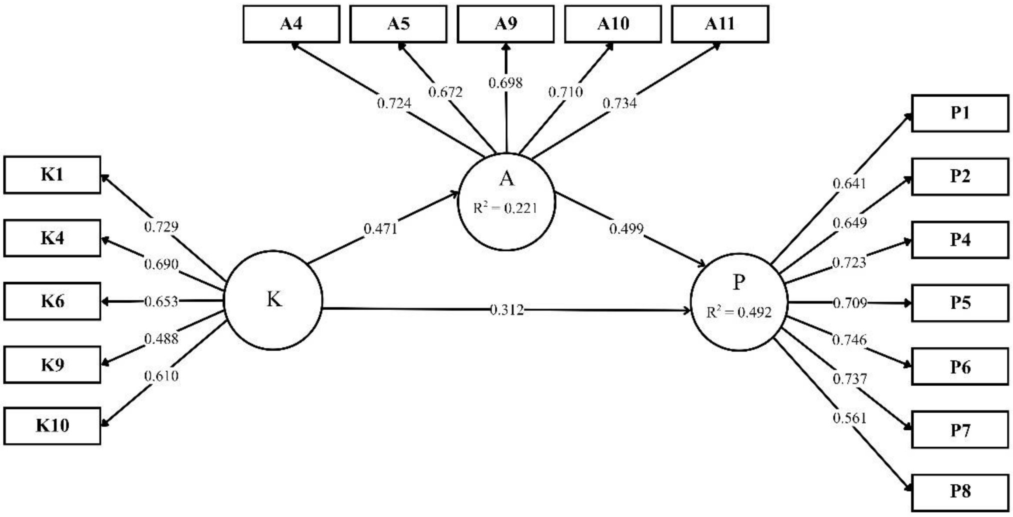

Figure 2. Partial least squares structural equation model of knowledge (K), attitudes (A), and practices (P) toward buffalo meat safety. The circles represent latent constructs with their R^2 values, the rectangles represent observed indicators with standardised loadings, and the arrows between the constructs show the standardised path coefficients.

4.6. Predictive performance of the PLS-SEM model

Although the structural model confirmed the hypothesised relationships among the KAP constructs, it is necessary to assess the predictive capability of the model to determine its practical utility. Therefore, PLSpredict was used to evaluate out-of-sample predictive performance (Table 7). Following prediction-oriented assessment principles for PLS-SEM [15], the model produced lower MAE and RMSE values than the linear benchmark across all indicators of attitudes and practices, and thus had superior predictive power. All Q^2_predict values were greater than zero, indicating meaningful out-of-sample predictive relevance, as recommended by Shmueli et al. [16]. These results confirm that the model can generate credible predictions for new observations, a key expectation in contemporary prediction-focused SEM that aims to integrate explanation and prediction [17,33]. The consistently high Q^2_predict values observed in this study suggest that the KAP–PLS-SEM model is theoretically robust and practically relevant regarding the prediction of behavioral outcomes.

This predictive capacity is particularly relevant in the context of buffalo meat consumption in Northern Thailand, given the strong influence of cultural norms, sensory preferences, and habitual purchasing behaviors on consumer choices. These culturally embedded preferences can be predicted once the attitudinal and perceptual pathways have been modelled properly [17,33]. The explanatory and predictive value of the proposed KAP–PLS-SEM model can be used to design targeted interventions that improve risk communication and communicate policies related to meat safety in culturally diverse consumption settings.

Table 7. Predictive performance of the partial least squares structural equation model.

Indicator	MAE (model)	MAE (benchmark)	RMSE (model)	RMSE (benchmark)	Q^2_predict
A4	0.573	0.667	0.773	0.982	0.044
A5	0.554	0.676	0.752	0.966	0.070
A9	0.553	0.694	0.712	0.940	0.090
A10	0.528	0.686	0.716	0.963	0.075
A11	0.610	0.748	0.774	1.012	0.100
P1	0.445	0.514	0.508	0.625	0.153
P2	0.424	0.521	0.488	0.647	0.162
P4	0.431	0.535	0.490	0.626	0.190
P5	0.415	0.502	0.466	0.671	0.114
P6	0.408	0.490	0.489	0.613	0.214
P7	0.404	0.487	0.495	0.634	0.208
P8	0.438	0.524	0.509	0.677	0.107

*Note: For all indicators, the partial least squares structural equation model yields lower prediction errors (mean absolute error [MAE] and root mean square error [RMSE]) than the linear benchmark model, and all Q^2_predict values exceed zero, indicating meaningful out-of-sample predictive power.

4.7. Theoretical implications

Our findings reinforce the theoretical relevance of KAP-based behavioral models within the context of livestock consumption. First, the strong correlations between knowledge, attitudes, and practices suggest that these constructs interact as part of an integrated appraisal system rather than as a simple linear sequence. The fact that the relationship between attitudes and practices is strongest underscores the primary role of affective processes in shaping livestock-consumption behaviors, consistent with the theory of planned behavior [10] and more recent livestock-focused behavioral evidence [29]. Second, the presence of the direct and indirect knowledge → practices pathways indicate that behavioral change emerges from the interplay between cognitive information and attitudinal evaluation. This finding is consistent with SEM-based KAP studies showing that knowledge exerts its strongest effect when it is internalised as positive attitudes toward food safety and risk-related issues [32,37,38]. Third, the model demonstrated strong predictive validity, with all Q^2_predict values greater than zero. This ability is in line with the methodological shift toward behavioral models that are explanatory and predictive and thus relevant for real-world decision-making [15,26]. Finally, by applying the KAP framework to the consumption of buffalo meat, a culturally embedded yet understudied livestock product, we extend behavioral theory to a new domain in which cognitive, affective, and risk perception processes jointly shape consumer choice.

4.8. Practical implications

The results provide several practical routes for improving buffalo meat safety in Northern Thailand. First, attitude-based interventions should be utilized, which involves freshness, sensory quality, and anticipated taste, which are highly linked to safer consumption patterns. However, specific food safety education, especially on pathogen risk, hygienic handling, and nutritional and cultural applicability of buffalo meat, needs to be offered. The predictive ability of the proposed KAP–PLS-SEM can also be used to tailor the communication strategies to specific audiences.

The results are also relevant for upstream actors: They indicate the need for farm- and slaughter-level improvements in smallholder and informal systems (e.g., better slaughterhouse hygiene, cold-chain infrastructure, and technical training through the Department of Livestock Development). Community-based certification schemes, such as the Livestock OK programme, along with the development of premium market channels, could help build trust and generate price incentives for safer production. Vendor training and stronger market oversight are also important, as consumer confidence and vendor reliability are central determinants of purchasing behavior. Nevertheless, we relied on self-reported behavioral data, which may be subject to social desirability bias. Participants may have overreported socially desirable food safety practices or underreported unsafe behaviors. Therefore, our findings should be interpreted with caution, and future studies may incorporate observational or longitudinal approaches to further validate consumer practices.

In addition, the findings should be interpreted within the cultural and livestock consumption context of Northern Thailand. Although the behavioral relationships identified in this study may provide useful insights for similar livestock-based food systems in LMICs, direct generalization to other regions or livestock products should be made with caution.

5. Conclusions

This study represents the first empirical investigation to apply an integrated KAP framework, using PLS-SEM, to examine buffalo meat safety behavior at the consumer level in Northern Thailand, an area with limited consumer-level evidence. Based on the findings, safety-related behavior among consumers is moderate, and knowledge influences these behaviors primarily through the formation of attitudes. Indeed, attitudes are the most significant predictor of behavior, underscoring the dominant role that affective and perceptual processes play in livestock-derived food safety practices. The structural model has shown a high level of explanatory and predictive performance, and its stability among demographic subgroups is an indication that behaviors are more important in the formation of safety practices as opposed to demographics.

These findings have significant implications for regulatory food safety authorities, community health workers, and livestock extension services. Interventions based on information do not suffice; positive attitudes should be promoted and risk perceptions enhanced to accelerate the changes in consumption patterns. Such an effort can be more fruitful in case it is founded on behavior (e.g., frequent consumers and those who prepare raw meat) than demographics. The accuracy of predicting the model also implies that the model can be used in data-driven monitoring devices or in mobile-based applications to aid in the process of handling meat safely in rural settings.

In general, this research satisfies one of the most important gaps in research on the topic of buffalo meat safety behavior, provides a theoretical contribution to consumer decision-making in animal-based food systems, and offers a behavioral model that can be extended to other LMICs livestock products. Evidence-based communication, education, and policy interventions grounded in this analytical model can be used to strengthen food safety outcomes.

Author contributions

W. Kusalaruk: Conceptualization, supervision, visualization, validation, writing–original draft, writing–review & editing; H. Nimitkeatkai: Conceptualization, supervision, and validation; P. Intawicha: Funding acquisition, project administration; S. Sakphoowadon: Conceptualization, supervision, validation; S. Saengwong: Conceptualization, data curation, formal analysis, methodology, validation, supervision, writing–original draft, writing–review & editing. All authors have read and approved the final version of the manuscript for publication.

Use of AI tools declaration

During the preparation of this work the authors used ChatGPT as a supportive tool to assist with language editing and grammatical refinement during manuscript preparation.

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Conflict of interest

The authors declare they have no conflict of interest in this article.

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