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REVIEW ARTICLE

A systematic literature review on factors influencing the adoption of crop residue among cattle farmers in Asia

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ABSTRACT

Asian countries face a significant shortfall in domestic beef production that fails to meet the demands of their populations, resulting in a heavy reliance on beef imports. This production gap is mainly due to the lack of feed resources. In response, Asian governments have introduced the concept of adopting crop residues as an alternative cattle feed. However, a shortage of comprehensive studies reviewing the adoption of crop residues among cattle farmers in Asia remains. To address this, a systematic literature review was conducted, integrating multiple research designs and following the ROSES (Reporting Standards for Systematic Evidence Syntheses) framework, with articles sourced from Scopus, Web of Science, and Google Scholar. Six key themes influencing the adoption of crop residues were identified: 1) demographic factors, 2) internal factors, 3) external factors, 4) economic factors, 5) extension services, and 6) farm-related factors, further categorised into 21 sub-themes. This study offers significant contributions to practical applications and academic knowledge, emphasising the need to examine the factors influencing the adoption of crop residues and the role of government policies. It also recommends the development of adaptation strategies tailored to the needs and capabilities of cattle farmers and highlights specific research areas that should be prioritised in future studies.

1. INTRODUCTION

The beef cattle industry in Asia remains relatively underdeveloped compared to other agricultural sectors, with domestic production in many countries meeting only 20–25% of total consumption requirements (Sandström et al., 2024). Rapid population growth, urbanisation, and rising incomes have driven sustained increases in demand for red meat; however, local production systems have struggled to respond effectively. Consequently, many Asian countries rely heavily on imported beef, exposing national food systems to external market volatility and price fluctuations. In Malaysia, for instance, the National Beef Industry Development Strategic Plan (2021–2025) aimed to achieve 50% self-sufficiency in beef production by 2025. Despite these efforts, progress has been limited, with import dependency remaining high, reflecting persistent structural weaknesses within the regional beef cattle industry (Yoon et al., 2024).

These structural constraints include limited availability of grazing land, fragmented smallholder-based production systems, and high production costs, along with underdeveloped breeding and genetic improvement programmes. Among these, the shortage of affordable, accessible, and sustainable feed resources has been consistently identified as one of the most critical factors limiting productivity and sectoral expansion. Feed costs often represent the largest share of total production expenses, particularly for smallholder farmers dominating cattle production systems across Asia. The urgency of addressing feed-related challenges is underscored by projections that demand for red meat in developing Asian countries is expected to double by 2050 from demographic growth and changing dietary patterns (Galanakis, 2024).

Evidence from several Asian countries illustrates the severity of feed constraints. In Indonesia, local beef production satisfies only about 45% of national demand, largely due to the scarcity of Napier grass, a key forage resource (Habte et al., 2020). In Laos, where approximately 98% of cattle are raised by smallholders, feeding relies heavily on traditional systems using untreated, low-quality crop residues, resulting in poor nutrition and low productivity (Tiemann & Douxchamps, 2023). Similar challenges are

observed in Thailand and Malaysia, where small-scale farmers face difficulties accessing quality feed and are constrained by rising input prices. Collectively, these cases highlight feed availability and affordability as a binding constraint on beef production in Asia.

Within this context, agricultural crop residues such as oil palm fronds, paddy straw, maize stover, and pineapple waste have emerged as a sustainable alternative feed resource. When appropriately processed into silage, bran, pellets, or treated fodder, crop residues can provide a more reliable and cost-effective feed supply while reducing agricultural waste. Their utilisation also contributes to improved resource efficiency and environmental sustainability, aligning with the Sustainable Development Goals, particularly Zero Hunger and Climate Action (Tchonkouang et al., 2023). Despite these benefits, adoption remains limited and uneven across Asian countries. Farmers face multiple barriers, including limited awareness of processing techniques, lack of technical skills, labour constraints, and insufficient access to extension services and institutional support. In addition, residues are often underutilised or used in raw form, offering minimal nutritional value and productivity gains.

While technical and nutritional studies on crop residue use are abundant, social science-oriented research on adoption behaviour is comparatively scarce. Understanding why farmers adopt or fail to adopt crop residue feeding requires engagement with innovation and adoption theories. Rogers' Diffusion of Innovations framework, for instance, explains how innovations spread through stages of awareness, evaluation, trial, and adoption, influenced by factors including relative advantage, compatibility, complexity, trialability, and observability. Complementary socio-economic adoption theories highlight the roles of farmer characteristics, access to information, institutional support, and enabling policy environments. However, the application of these theoretical perspectives to crop residue utilisation in Asian cattle feeding systems remains fragmented and inconsistent. Existing studies are often context-specific and methodologically diverse, focusing primarily on technical or nutritional aspects rather than adoption behaviour. This fragmentation limits policymakers, extension agents, and development practitioners in designing effective interventions to promote sustainable feed practices and improve regional beef self-sufficiency.

Hence, this study undertakes a systematic literature review, guided by the ROSES (Reporting standards for Systematic Evidence Syntheses) protocol, to synthesise evidence on factors influencing the adoption of crop residues as cattle feed in Asia. Specifically, it seeks to (1) Identify and categorise socio-economic, technical, institutional, and behavioural factors affecting adoption, (2) Analyse common drivers, constraints, and enabling conditions across diverse Asian contexts, and (3) Provide a theory-informed and policy-relevant synthesis to support targeted interventions, strengthen extension strategies, and advance sustainable cattle feeding systems in the region. By addressing these objectives, this study fills a critical gap in the comprehension of complex mechanisms shaping farmers' adoption decisions, offering relevant insights across the diverse agricultural landscapes of Asia.

2. MATERIALS AND METHODS

2.1. Review protocol-ROSES

This study followed the ROSES protocol to guide the systematic literature review process. ROSES is specifically designed for systematic reviews and evidence mapping in environmental management and related disciplines (Haddaway et al., 2018). Since the concept of crop residue is strongly embedded within environmental and agricultural research, ROSES was considered the most appropriate framework for this review. The protocol emphasises transparency, reproducibility, and methodological consistency by requiring clear reporting of research questions, search strategies, screening procedures, quality appraisal, and data synthesis methods.

In accordance with ROSES guidelines, the review process consisted of several sequential stages: formulation of research questions, systematic literature searching, article screening using predefined inclusion and exclusion criteria, eligibility assessment, quality appraisal of selected studies, as well as data abstraction and synthesis. While alternative protocols like PRISMA, the Cochrane Collaboration Guidelines, and EPPI-Centre methods are widely used, these frameworks are primarily oriented towards health sciences, experimental designs, or resource-intensive mixed-method reviews. In contrast, ROSES offers a flexible yet rigorous structure that is well-suited to agricultural and environmental research, where evidence is often heterogeneous and includes qualitative, quantitative, and mixed-method studies.

2.2. Formulation of research question

The research question was formulated using the PICo framework, which is commonly applied in systematic reviews to structure research questions in non-clinical contexts. PICo focuses on three core components: Population, Interest, and Context. In this study, the population comprised cattle farmers, the interest was the adoption of crop residues as cattle feed, whereas the context was cattle farming systems in Asia. Based on these components, the guiding research question was produced: What factors

influence the adoption of crop residue as cattle feed among cattle farmers in Asia?

2.3. Systematic searching strategies

The systematic searching strategy involved three primary processes: identification, screening, and eligibility (Figure 1).

2.3.1. Identification

The identification stage involved developing comprehensive search strings based on key concepts derived from the research question. Keywords and their synonyms were generated through online thesauruses, prior literature, database-generated suggestions, and expert recommendations, following the approach outlined by Booth (2016). Meanwhile, Boolean operators, phrase searching, truncation, and wildcards were applied to enhance search sensitivity.

Searches were conducted using Scopus and Web of Science as primary databases owing to their advanced search capabilities, extensive multidisciplinary coverage, and strong quality control mechanisms (Mohamed Shaffril et al., 2020). Google Scholar was used as a supplementary database to capture additional relevant studies, particularly those not indexed in subscription-based databases. Google Scholar is effective in retrieving a broad range of scholarly materials, including journal articles from established publishers (Gusenbauer & Haddaway, 2020; Hiebl, 2023). Search strings were tailored to each database (Table 1). The combined searches across the three databases yielded a total of 400 articles.

Table 1: Search string.

Database	Search string
Scopus	TITLE-ABS-KEY (("crop residue*" OR "Corn*" OR "Pineapple*" OR "agricultur* by-product*" OR "oil palm*" OR "rice straw*" OR "paddy*" OR "Crop waste*" OR " crop husk*" OR "utilize*") AND ("feed*" OR " local feed*" OR "pellet*" OR "silage*" OR "forage*") AND ("cattle* beef*" OR "ruminant*" OR "beef cattle*" OR " bovine*" OR "sheep*" OR " calf*") AND ("climate* change*"))
Web of Science	TS= (("crop residue*" OR "Corn*" OR "Pineapple*" OR "agricultur* by-product*" OR "oil palm*" OR "rice straw*" OR "paddy*" OR "Crop waste*" OR " crop husk*" OR "utilize*") AND ("feed*" OR " local feed*" OR "pellet*" OR "silage*" OR "forage*") AND ("cattle* beef*" OR "ruminant*" OR "beef cattle*" OR " bovine*" OR "sheep*" OR " calf*") AND ("climate* change*"))
Google Scholar	allintitle: ("crop residue") (Corn OR Pineapple OR agriculture by-product OR oil palm OR rice straw OR paddy OR Crop waste OR crop husk OR utilize) (feed OR local feed OR pellet OR silage OR forage) (cattle beef OR ruminant OR beef cattle OR bovine OR sheep OR calf)

2.3.2. Screening

All 400 selected articles were screened by applying automatic selection criteria through the sorting function available in the database. The criteria were based on the research question, following recommendations by Mohamed Shaffril et al. (2021). Given the impracticality of reviewing all existing published articles, Kucińska-Landwójtowicz et al. (2024) advised defining a specific time range for their review. According to Tiwari & Madalli (2021), a timeline restriction should only be applied if relevant studies are known to have been published within a particular period. The search in the selected databases showed an increase in studies on factors affecting the adoption of crop residue as cattle feed among beef farmers from 2009 to 2024. The year 2009 was chosen as the starting point due to the study's maturity period, with a 15-year span selected due to limited accessible references. Thus, the timeline from 2009 to 2024 was set as an inclusion criterion. Additionally, to ensure the quality of the review, only articles with empirical data and published in journals were included. Articles had to be published in English to avoid misunderstandings, and only those published in Asian countries were selected (Table 2). This process excluded 140 articles that did not meet the inclusion criteria and removed 23 duplicate articles. The remaining 237 articles were used for the third process, which is eligibility.

2.3.3. Eligibility

During this stage, articles were manually reviewed based on titles and abstracts. Studies were excluded if they did not directly address factors influencing the adoption of crop residues as cattle feed or lacked methodological clarity. A total of 226 articles were excluded for reasons of focusing on laboratory or nutritional analysis, adoption barriers rather than adoption processes, having unclear methodology, or a review-based format. Ultimately, 11 articles met the eligibility criteria and were included in the review.

Despite the relatively small number of studies, the strict inclusion criteria and focus on thematic saturation ensured sufficient data to identify consistent patterns across studies. The limited number of studies is justified by the highly specific research focus and the need for high-quality, contextually relevant data.

2.4. Quality appraisal

The remaining articles were presented to two experts for quality assessment, following Paul et al. (2021). Each article was categorised as high, moderate, or low quality based on methodological rigour, clarity, and relevance. Only studies rated as high or moderate were included. Disagreements between the experts were discussed and resolved, resulting in one high-quality and ten moderate-quality studies being included.

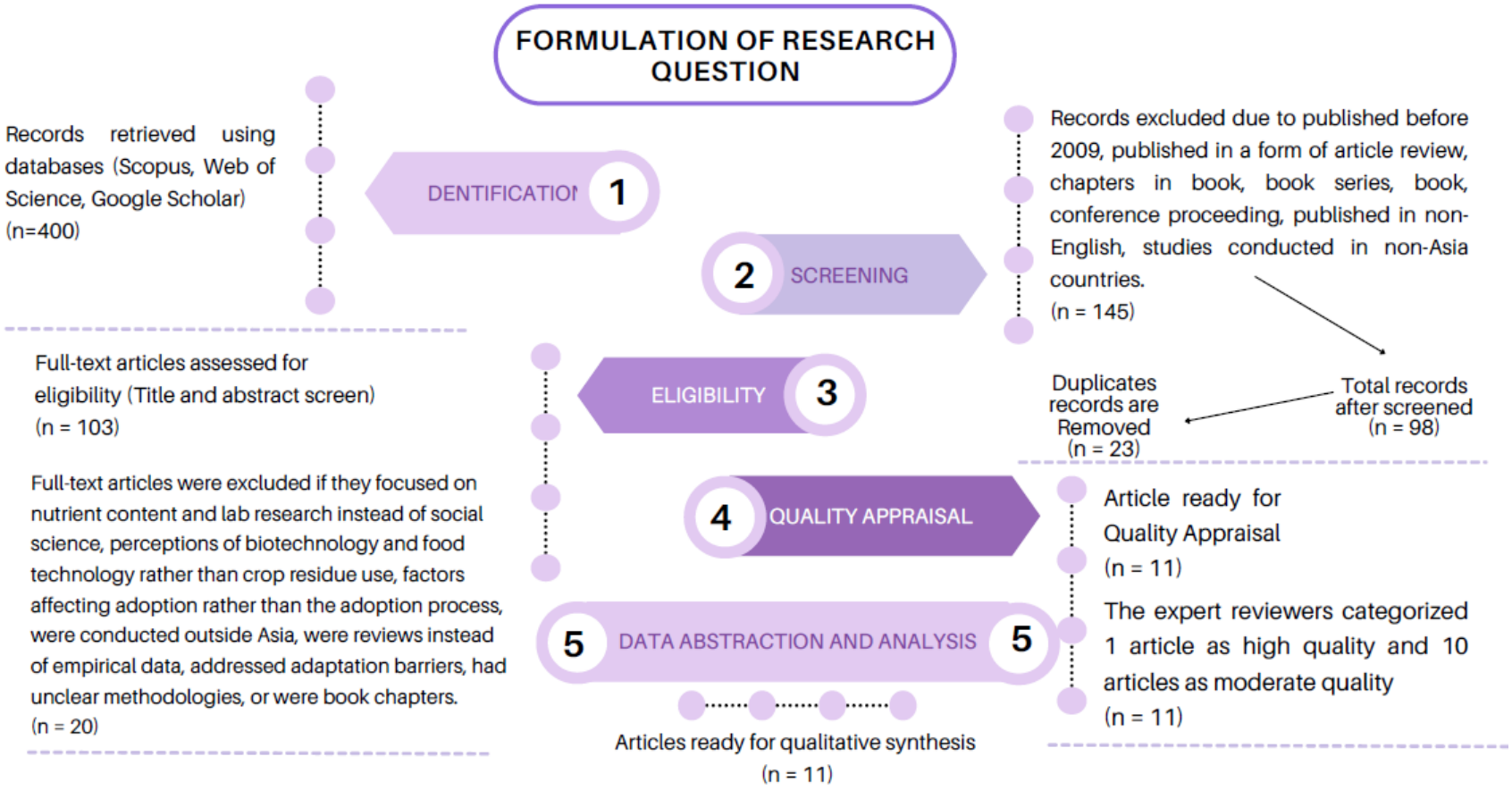

Figure 1: Formulation of research question.

Table 2: The themes and the sub-themes.

Studies	Years	Region	Demographic			Internal					External		Economic			Extension Services				Farm	
			A	Edu	Exp	HS	N	SN	NoL	LoM	Att	AtI	MI	CRFI	CRP	LW	FtF	EA	AoT	CT	NoC	LS	TD
Widarni et al.	(2021)	Indonesia	/	/	/	/				/								/	**	***	/	*	
Yuhendra et al.	(2022)	Indonesia	/	***	/	/								*	/		**	****				/	
Widarni et al.	(2020)	Indonesia	/	*	**												/			**	/	/	
Baba et al.	(2019)	Indonesia	/	*	**			**										**			**	**	**
Baba et al.	(2021b)	Indonesia				**	*										/						
Sudrajat et al.	(2020)	Indonesia	*	/								/											/
Raza et al.	(2019)	Pakistan						***			***												
Syahdar, Baba & Sohrah	(2019)	Indonesia	/			/						**									**		
Widarni et al.	(2020)	Indonesia	/	/	*	/			/	*							***		**	*	/	/	
Putra et al.	(2019a)	Indonesia	*	/		/																**	
Widarni et al.	(2020)	Indonesia	*	/	*			/	/	/				/				*	*	***	**	/	

Demographic
A= Age
Edu= Education
Exp= Experience

Internal Factor
HS=Household Size
N=Neighbour
SN=Subjective Norm

External Factor
NoL= Number of Labour
LoM= Length of Membership
Att= Attitude
AtI= Access to Information

Economic Factor
MI= Main Income
CRFI= Crop Residue Farming Income
CRP= Crop Residue Productivity
LW= Labour Wages

Extension Services Factor
FtF= Farmer to Farmer
EA= Extension Agent

Farm Factor
AoT= Amount of Training
CT= Cattle Type
NoC= Number of Cattle
LS=Land Size
TD=Technology Difficulties

2.5. Data abstraction and analysis

An integrative review approach was adopted, enabling the inclusion of quantitative, qualitative, and mixed-method designs. Data were abstracted from abstracts, results, and discussion sections of the 11 studies and organised according to the research questions. This was followed by deductive thematic analysis to identify main themes and sub-themes (Åkerblad et al., 2021; Christou, 2023).

Thematic analysis involved grouping similar findings, identifying six main themes and 35 initial sub-themes. After reviewing relevance and accuracy, six sub-themes were excluded, resulting in six main themes and 21 sub-themes. Themes were discussed among the authors to resolve inconsistencies and validated by two experts in qualitative and community development research, further confirming the appropriateness and relevance of the final thematic structure.

3. RESULT AND DISCUSSION

3.1. Background of selected article

This review analysed 11 selected articles and identified six key themes through thematic analysis: demographic factors, internal factors, external factors, economic factors, extension services factors, and farm factors. Further examination of these themes revealed 21 sub-themes. Among the 11 articles, 10 were conducted in Indonesia and one in Pakistan. Despite the geographical differences, data from both countries were included as they are both in Asia. The publication years of the articles were distributed as follows: 4 in 2019, 4 in 2020, 2 in 2021, and 1 in 2022.

3.2. The themes and sub-themes

3.2.1. Demographic factor

A demographic factor refers to the statistical characteristics of a population used in social studies, marketing, and research. These characteristics often include age distribution, gender proportion, income levels, educational attainment, occupation types, and marital status.

3.2.1.1. Age

Age is an important demographic factor influencing farmers' adoption of crop residues as feed. Studies reported mixed results regarding its effect. For instance, Baba et al. (2021), Syahdar Baba & Sohrah (2019), Widarni et al. (2020), and Yuhendra et al. (2022) found no significant impact of age on adoption. The average age of primary farmers in these studies was approximately 54.16–54.68 years, considered within the productive age range. Widarni et al. (2021) noted that although adopters tended to be younger than non-adopters, the difference was not statistically significant. Similarly, in Bantimurung and Mallawa sub-districts, age differences among farmers did not affect adoption (Baba & Sohrah, 2019).

Conversely, other studies observed a negative relationship between age and adoption. Putra et al. (2019), Sudrajat et al. (2020), and N. A. A. Widarni, Kusumastuti, et al. (2020) discovered that older farmers were less likely to adopt crop residues due to declining physical capacity and shifting priorities toward family survival. Older farmers may also be less willing or able to experiment with innovations, while younger farmers are more likely to adopt new techniques, such as mixed-crop livestock (MCL) practices (Widarni et al., 2020). Nonetheless, some research suggests age is not necessarily a barrier if farmers receive sufficient training and support, as seen during the COVID-19 pandemic, when older farmers adopted new practices when benefits were clear (Jacob et al., 2022). This indicates that adoption is influenced not just by age but also by the interplay of experience, training, and perceived benefit.

3.2.1.2. Education

Education affects farmers' awareness, decision-making, and access to information, thereby influencing the adoption of crop residues. Several studies reported positive effects of education on adoption. For instance, Widarni et al. (2020) and Yuhendra et al. (2022) mentioned that higher education levels increased farmers' capacity to adopt integrated farming systems and utilise crop residues effectively. Šūmane et al. (2018) similarly highlighted that education enhances access to information and improves the adoption of sustainable practices.

However, results were not uniform. Yuhendra et al. (2022) noted a negative effect of higher education on adoption intentions for oil palm-cattle integration, while Kim et al. (2022) found no significant impact of the education or career of farmers' spouses on adoption. Meanwhile, studies in Indonesia (Widarniet al., 2020; Putra et al., 2019; Sudrajat et al., 2020) showed no significant differences in adoption rates based on formal education. Factors such as cost, risk aversion, or the need for specialised expertise can inhibit adoption despite adequate education. Notably, adopter farmers typically possess higher education, larger farms, and greater access to information compared to non-adopters (Widarni et al., 2021), highlighting how education interacts with farm-level and economic factors.

3.2.1.3. Experience

Farming experience can influence adoption by shaping farmers' knowledge, skills, and familiarity with farm management practices. Widarni et al. (2021) reported that experience did not directly affect the adoption of rice by-products, though experienced farmers were more likely to adopt crop residues when provided with appropriate training.

Similarly, Baba et al. (2019) found that the adoption of agricultural by-products in Maros Regency, Indonesia, was limited by feed availability rather than experience.

In contrast, other studies indicated a positive relationship between experience and adoption. Widarni et al. (2020, 2021) presented that more experienced farmers were more inclined to adopt mixed-crop livestock systems and integrate crop residues into feed practices. Each additional year of experience slightly increased the likelihood of adopting integrated farming practices (marginal effect ≈ 0.03%). Farmers with greater experience also tend to recognise the inefficiencies of non-integrated systems and the potential profitability of crop residue utilisation (Paul et al., 2017; Sarkar et al., 2020). This suggests that experience interacts with economic, technological, and training factors to influence adoption.

Nevertheless, the demographic factors of age, education, and experience do not operate in isolation. Their effects are mediated by farm size, availability of resources, access to training, and perceived economic benefits. For example, younger or more educated farmers may adopt innovations more readily when training and extension services are available. Conversely, older or less formally educated farmers can still adopt crop residue practices if support structures reduce the physical, financial, and cognitive barriers to adoption. Highlighting these interactions underscores adoption as a multi-dimensional and context-dependent process, rather than being determined by demographic characteristics alone.

3.2.2. Internal Factor

3.2.2.1. Household size

Household size has been examined as a potential internal factor influencing the adoption of crop residues as cattle feed. Several studies, including Baba and Sohrah (2019), Putra et al. (2019), Widarni et al. (2020; 2021), and Yuhendra et al. (2022), found that household size did not significantly affect adoption behaviour. In contrast, Baba et al. (2021) argued that household size significantly influenced the adoption of paddy straw as cattle feed. These mixed findings suggest that the role of household size may be context-dependent, influenced by other factors such as labour availability, farm size, and socio-cultural norms.

The influence of family members on technology adoption is also noteworthy. Farmers often make decisions within a social context where family members and neighbours act as reference groups, shaping perceptions and behavioural patterns (Torre et al., 2020). In the Barru district, for example, rice straw adoption was positively correlated with the support and influence of family and neighbours. Larger households may have more labour resources for activities like collecting and processing crop residues, potentially increasing adoption likelihood.

3.2.2.2. Neighbour

Neighbours play a critical role in farmers' adoption decisions, though several studies have explicitly included this variable. Baba et al. (2021) found that neighbours significantly influenced the adoption of paddy straw among farmers. Neighbouring farmers provide opportunities for discussion, knowledge exchange, and collaborative activities such as collecting rice straw during harvest season (Sereenonchai & Arunrat, 2022). Observing peers successfully adopt and use new technologies often motivates other farmers to follow suit, demonstrating the practical importance of social learning in adoption behaviour (Li et al., 2023; Sapbamrer & Thammachai, 2021).

3.2.2.3. Subjective norm

Subjective norms, defined as perceived social pressure to perform or not perform a behaviour, significantly shape adoption decisions. In other words, farmers may adopt crop residue practices if they perceive expectations from key social referents such as family, neighbours, or agricultural advisors to do so (Baba & Sohrah, 2019; Raza et al., 2019). Social interactions, cooperation, and peer observation can encourage adoption, while negative perceptions or discouragement may inhibit it (Abid et al., 2014).

However, the influence of subjective norms is not uniform across contexts. For example, Widarni et al. (2020) found no significant impact of subjective norms on adopting mixed cropping systems integrating livestock, highlighting that cultural, institutional, and technological contexts can moderate their effect. In the Barru district, the presence of advanced farmers demonstrating the use of rice straw significantly enhanced adoption. Transforming extension activities from lecture-based formats to practical demonstrations can further strengthen the influence of subjective norms and peer learning on adoption behaviour.

Integration across internal, demographic, and social factors revealed the adoption of crop residues as a multi-dimensional process. Household size, neighbour influence, and subjective norms do not operate in isolation; they interact with economic incentives, technological readiness, and institutional support to shape farmer decisions. For example, larger households with strong social networks may be more likely to adopt crop residue technology when combined with access to demonstration plots and extension services.

The relative importance of these internal factors varies by context. Neighbour influence and subjective norms consistently emerge as critical facilitators of adoption,

especially in culturally tight-knit rural communities, whereas household size shows mixed effects depending on labour availability and social structure.

Contextualising these findings within Asian smallholder farming systems presents unique challenges and opportunities. Features such as land fragmentation, labour constraints, informal knowledge networks, and heterogeneous policy environments influence how internal factors translate into adoption behaviour. Hence, understanding these interactions is essential for designing effective interventions to promote sustainable crop residue utilisation.

3.2.3. External factor

3.2.3.1. Number of labourers

Sudrajat et al. (2020) illustrated that the number of available labourers did not significantly impact the adoption of rice straw as cattle feed, largely due to the household head, typically the husband, often having additional work outside the farm, thus limiting his ability to collect feed materials. While wives or other family members sometimes assist in livestock care, their availability is inconsistent due to other responsibilities. Lisson et al. (2010) emphasised that women play a crucial role in accessing information, controlling resources, and making decisions in beef cattle operations integrated with crop production.

Hiring additional labour could address feed collection challenges; however, small-scale farmers often avoid this due to the perceived high-cost relative to their income, especially when they have few livestock. Neethirajan & Kemp (2021) highlighted that the scale of livestock production influences business efficiency, with larger herds benefiting from reduced per-unit production costs. This aligns with findings from Widarni et al. (2020), who reported that family labour had minimal impact on mixed crop-livestock farming in Magelang Regency, Central Java. In such systems, family members typically assist with feeding to reduce operational costs.

3.2.3.2. Length of membership

Widarni et al. (2020) investigated the relationship between group membership duration and adoption of mixed crop-livestock (MCL) technologies. They revealed that longer membership periods were positively associated with the adoption of practices like utilising crop residues as cattle feed. Prolonged group involvement exposed farmers to new knowledge, particularly regarding effective crop residue use, fostering innovation in livestock feeding practices (Tesfaye et al., 2021).

However, subsequent studies by Widarni et al. (2021) and Widarni et al. (2020) reported no significant impact of membership duration on technology adoption. Barriers included the cost of adopting new technologies, which small-scale farmers often cannot afford (Sereenonchai & Arunrat, 2022), and disparities in technical capacity and equipment, limiting effective crop residue utilisation (Mizik, 2023). These factors suggest that while group membership can facilitate knowledge exchange, its influence on adoption is contingent upon farmers' resources and technological readiness.

3.2.3.3. Attitude

Raza et al. (2019) presented a significant relationship between farmers' attitudes and their adoption of sustainable crop residue management practices. Farmers who were aware of the negative consequences of residue burning, including environmental degradation and health hazards, were more likely to adopt sustainable alternatives. Additionally, education amplified this effect, with more educated farmers demonstrating greater awareness of environmental risks and stronger willingness to engage in environmentally friendly practices (Raza et al., 2022).

Perceived risks such as regional smog linked to residue burning in Punjab, India, and Pakistan also influenced farmer behaviour, reinforcing the role of awareness and attitudes in adoption decisions. Government policies and initiatives by NGOs promoting cleaner production methods further motivated farmers to shift toward sustainable practices. Similar trends were observed in China, Vietnam, and Pakistan, highlighting the cross-regional relevance of attitude and risk perception in shaping crop residue management decisions (Raza et al., 2019).

3.2.3.4. Access to information

Baba and Sohrah (2019) found that access to information significantly influenced the utilisation of agricultural waste as cattle feed. Farmers in Mallawa perceived rice and corn straw, when supplemented with protein sources like peanut straw and legumes, as nutritionally adequate, whereas farmers in Bantimurung considered unprocessed agricultural waste insufficient. This highlights the critical role of knowledge about proper feed formulation in adoption decisions (Yang et al., 2021).

Conversely, Sudrajat et al. (2020) emphasised that access to technology, not just information, can limit adoption. Even well-informed farmers were reluctant to adopt crop residue feeding due to a lack of practical skills and demonstrations for processing rice straw. Effective adoption requires awareness and the ability to implement technology, underscoring the interaction between informational and technological factors in influencing behaviour (Sereenonchai & Arunrat, 2022).

External factors influencing crop residue adoption are multifaceted, interacting closely with internal, economic, and demographic factors. For instance, labour availability and

family structure (internal factor) intersect with the scale of operation (economic factor) to shape adoption potential. Similarly, attitudes and access to information (external factors) interact with education and awareness (demographic factors) to determine sustainable practice adoption. Recognising these interdependencies is essential for understanding adoption as a dynamic, multi-dimensional process within Asian smallholder farming systems.

3.2.4. Economic income

3.2.4.1. Main income

Widarni et al. (2021) found that farmers' primary income had no significant effect on the adoption of rice by-products as cattle feed. Conducted in Magelang Regency, Indonesia, the study revealed that over 80% of farmers rely on ruminant farming as their main occupation. Among these farmers, 80.90% who adopted rice by-products and 83.41% who did not still used this by-product in livestock feeding. In contrast, Cheng et al. (2022) observed that farmers managing larger plantation areas were more likely to use crop residues, motivated in part by concerns about environmental sustainability and resource optimisation. Similarly, Keno et al. (2021) highlighted that profit-oriented farmers are more inclined to adopt crop residues, as it aligns with their goal of maximising farm profitability. These findings indicate that while primary income alone may not determine adoption, economic incentives and resource efficiency considerations can motivate certain farmer groups.

3.2.4.2. Crop residue farming income

Income derived from farming activities, particularly through integrated systems, significantly influences adoption decisions. In a study by Yuhendra et al. (2022), it was found that oil palm farmers who integrated beef cattle production experienced higher incomes and were more likely to adopt integrated farming systems (IFS) than those with lower earnings. This is consistent with Lisson et al. (2010), who reported that barley farmers with higher incomes were more inclined to use barley straw as cattle feed. Wealthier farmers have the financial flexibility to invest in necessary technology and skilled labour, enabling them to convert crop residues into viable feed (Agbenyo et al., 2022). Conversely, lower-income farmers may face financial constraints that limit their ability to implement advanced practices (Kim et al., 2022). Thus, it shows that income disparities play a critical role in the differential adoption of sustainable agricultural practices, highlighting financial capacity as a key driver of innovation uptake.

3.2.4.3. Labour wages

Labour costs significantly affect farmers' willingness to use crop residues as feed. Sudrajat et al. (2020) observed a negative correlation between labour wages and the adoption of rice straw as cattle feed. In South Bontonompo District, Gowa Regency, farmers often avoid utilising rice straw due to the additional labour required for collection, transport, and processing (Balingbing et al., 2020; Kaniapan et al., 2021). As labour costs rise, farmers frequently resort to alternative, less labour-intensive methods, such as composting, leaving residues to decompose naturally, or open burning (Ayilara et al., 2020). While these alternatives reduce labour expenditure, practices like open burning present environmental trade-offs, including air pollution and the loss of valuable organic matter. These findings underscore the interaction between economic constraints and environmental considerations, illustrating how cost pressures can shape resource management decisions in smallholder farming systems.

Economic factors, like income level and labour costs, do not operate in isolation but interact with other determinants such as farm size, household labour availability, and environmental awareness. For instance, higher-income farmers may simultaneously benefit from larger landholdings and access to skilled labour, enabling more efficient adoption of crop residue utilisation. Conversely, farmers constrained by low income or high labour costs may prioritise immediate cost savings over sustainability, affecting adoption rates. Understanding these interactions highlights adoption as a multi-dimensional process shaped by economic, institutional, and farm-level contexts.

3.2.5. Extension services

3.2.5.1. Farmer to farmer

Yuhendra et al.'s (2022) study in Riau Province discovered that participation in farmer group associations significantly influenced the adoption of integrated farming systems. Interestingly, farmers who were members of groups or cooperatives were less likely to integrate oil palm with cattle farming, as indicated by a negative coefficient of -0.69. The odds ratio further showed that the probability of farmers adopting oil palm-cattle integration was 0.50 times lower among group members compared to non-members. This counterintuitive result may reflect the focus of many farmer groups or cooperatives on activities other than promoting oil palm-cattle integration (Bremer et al., 2022). Additionally, some farmers may opt out of group-based adoption since they already have substantial experience or motivation to implement integrated practices independently (Molina et al., 2021).

These findings align with Widarni et al. (2020), who suggested that while group membership can enhance access to information, such as interacting with extension agents or

participating in training, it is not always sufficient to drive adoption of specific technologies like crop residue utilisation. Similarly, Baba et al. (2021) found no significant relationship between farmer group participation and the adoption of crop residue technology in oil palm and paddy farming. Extension agents' influence on rice straw adoption as cattle feed was also minimal, indicating that traditional top-down training sessions were not the primary driver of adoption (Antwi-Agyei & Stringer, 2021).

In Barru District, fostering greater adoption of rice straw utilisation may require more localised, peer-driven approaches. Leading farmers who actively demonstrate the technology can inspire neighboring farmers, emphasising the importance of observational learning and reference groups (Hermans et al., 2023). Furthermore, extension programmes should transition from conventional lecture-based methods to practical demonstrations, which encourage active participation and peer-to-peer learning, thereby increasing adoption rates.

3.2.5.2. Extension agent

Extension agents also play a critical role in facilitating the adoption of integrated and sustainable farming technologies. Yuhendra et al. (2022) reported that farmers in Riau Province who dedicated more time to their farms and received frequent counselling from extension agents were more likely to adopt oil palm-cattle integration. Interaction with extension agents enhances farmers' access to recent agricultural information, which in turn increases the likelihood of adopting innovations (Ayisi Nyarko & Kozári, 2021).

Similarly, studies by Baba et al. (2019) in Maros Regency and Widarni et al. (2020) in Magelang Regency demonstrated the ability of extension services in significantly contributing to the adoption of rice and corn straw technologies as animal feed, as well as multi-crop-livestock (MCL) farming. Extension agents representing government agricultural programmes are crucial for disseminating technical knowledge and supporting farmers in making informed decisions.

However, the influence of extension agents varies depending on the technology. Widarni et al. (2021) highlighted that training sessions, rather than one-on-one consultations with agents, had a more significant impact on farmers' adoption of rice straw as feed. Practical demonstrations, often led by extension agents, enable farmers to learn and apply new techniques effectively (Amran et al., 2021). Baba et al. (2021) further emphasised that although extension workers may not be the primary information source for straw technology, training delivered by these agents substantially improves adoption rates. This suggests that extension services remain important, but their effectiveness depends on the nature of the technology, the delivery method, and farmers' prior knowledge.

3.2.6. Farm factor

3.2.6.1. Amount of training

Training plays a critical role in farmers' adoption of crop residues as cattle feed. A study by Widarni et al. (2021) found that farmers with training, often delivered through practical demonstrations and exercises by extension agents, were more likely to use rice straw as animal feed. Even though farmers rarely sought personal consultations with extension officers, the officers' role in demonstrating technical practices was pivotal. Participatory training, where farmers learn by observing and practicing, enhances their ability to make informed decisions on utilising rice by-products. Similarly, Widarni et al. (2020) mentioned that farmers who frequently attended training sessions acquired the necessary skills to implement integrated farming systems.

Education and training increase farmers' awareness and readiness to adopt new practices (Sapbamrer & Thammachai, 2021). Meanwhile, access to extension services, participation in farmer groups, and livestock-rearing experience collectively expand farmers' knowledge base, facilitating the adoption of manure-based crop-livestock (MCL) systems (Widarni et al., 2020). Regular consultation with extension agents provides guidance and technical support, which enhances adoption rates, especially when combined with practical experience. In particular, farmers with larger herds gain more benefits from MCL practices, as livestock manure becomes a valuable input for the system, demonstrating the interconnectedness of farm- and resource-level factors.

3.2.6.2. Cattle type

The type of ruminant raised significantly influences adoption. Widarni et al. (2021) in their study mentioned that farmers raising large ruminants such as beef cattle were 10.76 times more likely to use rice straw as feed compared to those raising small ruminants like goats or sheep. Large ruminants digest crude fibre more effectively, making crop residues a viable feed option (Boudalia et al., 2024). This aligns with Widarni et al. (2020), who observed interactions between livestock type and other factors such as extension consultation, training, and experience to shape adoption.

Additionally, larger landholdings, often associated with raising beef cattle, increase the capacity to adopt new technologies, whereas farmers with limited land and smaller livestock face constraints in resources and information (Kendall et al., 2022). These findings highlight how farm-scale characteristics, livestock type, and access to knowledge collectively influence adoption decisions.

3.2.6.3. Number of cattle

Furthermore, the herd size directly affects the likelihood of adopting crop residues as feed. Baba et al. (2019) found that farmers with larger herds were 2.328 times more likely to adopt rice and corn straws as feed. As livestock numbers rise, so does the feed demand, increasing reliance on crop residues. Processing methods, however, remain crucial due to the low nutritive quality of raw residues (Luciano et al., 2020). Regions prioritising food security, including Pasuruan, benefit from the integration of crop and livestock production, which facilitates feed availability (Parmawati et al., 2018).

Contrastingly, some studies (Widarni et al., 2020; 2021) found no direct significant relationship between herd size and adoption. Farmers practicing full integration generally have larger herds, more experience, and greater access to training and resources, suggesting that herd size may be a proxy for overall resourcefulness and adoption readiness rather than an independent driver.

3.2.6.4. Land size

Land size influences adoption in nuanced ways. While large-scale beef farmers may utilise crop residues more effectively owing to the ability of large ruminants to digest fibre (Widarni et al., 2021), other studies (Widarni et al., 2020) reported no significant effect of land size on adoption. Factors such as farmer education, experience, and willingness to experiment appear more critical than absolute landholding. Limited land resources often steer younger or resource-constrained farmers toward alternative livelihoods, indicating the socio-economic context as a mediating factor in adoption (Putra et al., 2019).

3.2.6.5. Technology difficulties

Technical constraints affect the practical adoption of crop residues. Baba et al. (2019) reported that greater difficulty in handling rice and corn straws reduces adoption, whereas Sudrajat et al. (2020) observed no significant effect of technological complexity. In South Bontonompo District, the absence of essential equipment, like chopper machines, makes manual processing labour-intensive and time-consuming, thereby limiting adoption (Kashyap et al., 2023). Introducing mini chopper machines can significantly reduce labour requirements, enabling farmers to process larger quantities efficiently and integrate crop residues into livestock diets more effectively (Ayisi Nyarko & Kozári, 2021; Luciano et al., 2020). This demonstrates how technological solutions can interact with farm-level characteristics such as herd size and available labour to influence adoption outcomes.

Nevertheless, farm-level factors do not operate in isolation. Training, livestock type, herd size, landholding, and technology access interact with demographic (age, education), economic (income, main occupation), and institutional factors (extension services, farmer groups) to shape adoption behaviour. For instance, well-trained farmers with larger herds and access to extension support are more likely to adopt crop residues, highlighting the multidimensional nature of adoption decisions. This underscores the need to view adoption as a complex interplay of farm capacity, resource availability, and institutional support rather than a linear outcome of a single factor.

4. RECOMMENDATIONS

This review identified several priority areas for future investigation on the adoption of crop residues as cattle feed in the Asian context. First, region-specific and cross-country comparative studies across diverse settings such as Malaysia, Thailand, India, China, Cambodia, and Laos should be given priority. Asia has lagged behind other regions in scholarly investigation and widespread implementation of crop residue utilisation. Hence, future research should place greater emphasis on socio-cultural, economic, and institutional determinants of adoption, particularly from a social science perspective. This includes examining behavioural norms, informal knowledge-sharing systems, and community decision-making processes that influence farmers' perceptions and practices.

Second, further empirical work is required to evaluate the role of crop residue utilisation in enhancing sustainable beef production and regional food security. Chronic feed shortages and inefficient resource use have contributed to declining cattle production in parts of Asia, with potential implications for the stability of supply chains. As noted by Luciano et al. (2020), current literature does not sufficiently quantify the extent to which crop residue adoption mitigates feed scarcity. Future studies should therefore measure practical outcomes such as feed availability, cost reduction, animal health, and productivity to provide robust evidence for policymaking.

Third, future research can adopt a balanced approach by assessing the benefits and potential trade-offs of adoption strategies. While existing studies emphasised positive effects that improved feed efficiency, cost savings, and environmental gains, less attention has been given to constraints such as high initial investment in processing technologies, limited access to extension services, and possible overreliance on government support. Such assessments should identify context-specific barriers, particularly for smallholder farmers, to ensure equitable and scalable adoption.

Finally, future investigations should employ interdisciplinary and multi-stakeholder approaches,

integrating technical, economic, cultural, and policy perspectives. Collaboration among agricultural scientists, social scientists, economists, policymakers, and farmer organisations will enable a more comprehensive understanding of the adoption process. This integration will improve the design of interventions and strengthen the potential for widespread, sustainable utilisation of crop residues as cattle feed across Asia.

5. CONCLUSION

This study has systematically reviewed the adoption of crop residues as cattle feed among cattle farmers in Asia, highlighting the key factors influencing their adoption behaviour. The findings indicated that adoption is driven by a complex interplay of four dimensions: (1) traditional knowledge and cultural norms, shaping perceptions and acceptance of new practices; (2) economic considerations, including cost savings, profitability, and market incentives; (3) technological and infrastructural access encompassing machinery, processing technologies, and digital information tools; and (4) institutional and policy support, which determines the scale and sustainability of adoption.

Traditional practices such as composting, direct feeding, and open burning of residues remain deeply embedded in many communities, reflecting intergenerational knowledge and strong social norms. While these practices provide familiarity and social continuity, they may slow the uptake of more efficient feeding solutions. Additionally, farmers with access to modern processing technologies, digital information systems, extension support, and targeted training exhibited greater adoption, illustrating the responsiveness of behaviour when cultural traditions are respected and tangible benefits are evident.

Institutional engagement is a decisive enabler. Cohesive agricultural policies, well-functioning cooperative networks, and robust extension services significantly increased adoption rates, whereas fragmented or inconsistent institutional support hindered farmers' exposure to innovations and capacity for residue utilisation. By integrating social, economic, institutional, and farm-level determinants within an Asian context using the ROSES framework, this review contributes a comprehensive synthesis that extends beyond prior studies, which often examine factors in isolation.

The findings suggest that a hybrid approach, one that preserves culturally significant practices while strategically incorporating science-based, resource-efficient methods, can enhance feed security, reduce reliance on beef imports, improve cattle productivity, and advance regional objectives of environmental sustainability, climate resilience, and food security.

6. AUTHOR CONTRIBUTION

All authors contributed to this study as follows: [Author 2] and [Author 3] conceptualised the study, while [Author 1] and [Author 2] developed the methodology. Data collection and analysis were conducted by [Author 1] and [Author 2]. [Author 1] and [Author 2] were responsible for the systematic review and data synthesis, and [Author 2] and [Author 3] prepared the original draft. [Author 1] and [Author 2] contributed to reviewing and editing the manuscript. Visualisation was handled by [Author 3], with [Author 2] overseeing the study. All authors read and approved the final manuscript.

7. DECLARATION OF COMPETING INTEREST

The authors confirm that this funding did not influence the study's design, methodology, analysis, interpretation of results, or the decision to publish. No competing financial interests or personal relationships exist that could be perceived as affecting the objectivity of this research. The authors have no affiliations, consultancies, stock ownership, advisory roles, or patent holdings that may impact the integrity of the research outcomes. All authors have adhered to ethical standards to maintain transparency and objectivity throughout the research process, ensuring the results presented are unbiased and solely intended for scientific advancement. Any other potential conflicts of interest were fully disclosed and addressed to uphold the highest ethical standards in research integrity.

8. DATA AVAILABLE STATEMENT

This study is a systematic literature review, and all data used in the analysis were obtained from publicly available research articles, databases, and other scholarly sources. The sources and studies included in this review are cited in the reference list. Since this research does not involve the collection of primary data, no additional raw data were generated. Any specific queries about the data supporting the findings of this review can be directed to the corresponding author.

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