Green Asia Report Series

No.7

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Shigeki Yokoyama [1], Yasuro Funaki [2], Koki Maeda [2], Junichiro Marui [2], Masanori Kozono [3]

1 Japan Agricultural Development and Extension Association (JADEA)
2 Japan International Research Center for Agricultural Sciences (JIRCAS)
3 Economic Research Institute for ASEAN and East Asia (ERIA)

March 2026

Green Asia

ISBN: 978-4-906635-28-3
https://doi.org/10.64096/gars-e.7

This work is a product of JIRCAS staff with external contributions and is based on a study conducted under the project "Accelerating application of agricultural technologies which enhance production potentials and ensure sustainable food systems in the Asia-Monsoon region", funded by the Ministry of Agriculture, Forestry and Fisheries, Japan.

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Summary

"Technology Catalog Contributing to Production Potential and Sustainability in the Asia-Monsoon Region" was developed under the Green Asia project launched in 2022. As a flagship product, it includes over forty scalable technologies developed in Japan or through international partnerships. The catalog was incorporated into the ASEAN-Japan MIDORI Cooperation Plan and has attracted significant interest.

To promote adoption, it is essential to conduct surveys and share results on the effectiveness of these technologies in specific countries. Two technologies considered closest to social implementation-cashew nutshell liquid feeding (CNSL) and maintaining fermented rice noodles in acidic conditions-were selected for pilot studies in the Asia-Monsoon region.

CNSL is expected to reduce enteric methane emissions from beef cattle by 20–23% in Thailand and 19–22% in Vietnam. Furthermore, even when considering total enteric fermentation, it is estimated that feeding CNSL to beef cattle could reduce enteric methane emissions by 14–17% in Thailand and 10–11% in Vietnam. This pilot study identified limitations and constraints in estimating the methane emission reduction ratio for Thailand and Vietnam, especially regarding available datasets. Further studies are required to improve the accuracy of the estimates.

Despite its potential, CNSL has not yet been commercially available in ASEAN countries. Regulatory approval by relevant government authorities is necessary to ensure its safety and effectiveness, and the establishment of a reliable supply chain by the private sector remains essential. In addition, the introduction of a carbon credit scheme could provide economic incentives for livestock industries.

Fermented rice noodles (FRN) are usually kept at ambient temperature and resist spoilage for a few days due to their acidic nature from rice fermentation. Refrigeration is discouraged, as it damages their texture through starch retrogradation. However, severe liquefaction sometimes occurs before market sales. The technology for maintaining an acidic condition to prevent the liquefaction of FRN could reduce food loss by 0.1-8.7% in Thailand and 10.1-12.7% in Vietnam, respectively. This study confirmed the issue in both Thailand and Vietnam, emphasizing the need for pH control. To prevent liquefaction and ensure product stability, it is advisable for public or industry bodies to publish technical guidelines.

By conducting pilot studies to measure the impact of applying technologies in local contexts as demonstrated in the study of CNSL and by identifying existing challenges through on-site investigations for FRN, it becomes possible to evaluate the significance of implementing technologies listed in the Technology Catalog. Similar assessments are strongly recommended for other scalable technologies included in the catalog particularly in supporting climate change mitigation and promoting sustainable development in the Asia-Monsoon region.

1: Introduction

Agriculture and associated land-use changes are estimated to generate approximately a quarter of global greenhouse gas (GHG) emissions (Tubiello, 2018). In the 2010s, Asia was the largest contributor to agricultural emissions (43%), increasing its share from the 1960s, while Europe reduced its share from 25% to 12%, and the Americas remained at 26% (Tubiello, 2018). From this perspective, the promotion and acceleration of application of agricultural technologies which increase production potential and ensure sustainability are urgently needed to mitigate climate change and ensure food security.
In the ASEAN region, where agriculture plays a crucial role in socio-economic development, improving the overall performance of the food systems is essential. The ASEAN Guidelines on the Promotion of Climate-Smart Agriculture (CSA) Practices (Vol. 3, ASEAN, 2022a), which emphasize the need to prioritize CSA approaches tailored to local climatic risks and agro-ecological conditions. The guidelines also highlight successful case studies such as climate-smart villages, low-emission livestock systems, and resilient aquaculture practices, providing a practical foundation for scaling up CSA in the region. Additionally, the ASEAN Regional Guidelines for Sustainable Agriculture propose strategies to reduce GHG emissions and minimize food loss and waste (ASEAN, 2022b).

Furthermore, in recent years, ASEAN Member States (AMSs) have developed several policy documents to address the growing challenges such as climate change, biodiversity loss, and low adoption of innovative technologies. One of the important documents is the Action Plan for Sustainable Agriculture in ASEAN, adopted at the 46th Meeting of ASEAN Ministers on Agriculture and Forestry (AMAF) in October 2024, highlighting five key priority areas including decarbonization, digitalization, climate change adaptation and mitigation, and public-private partnerships. In the Food, Agriculture and Forestry Sectoral Plan 2026-2030 adopted at the 47th AMAF on 1st October 2025, which is a cornerstone document for the ASEAN Food, Agriculture and Forestry (FAF) sectors development for the next five years, decarbonizing FAF sectors through reducing greenhouse gas emission is highlighted as one of the six Strategic Thrusts. Also, reducing and minimizing food loss and waste is still raised as an issue to be addressed.

In line with these regional efforts, the Japan International Research Center for Agricultural Sciences (JIRCAS) has published the "Technology Catalog Contributing to Production Potential and Sustainability in the Asia-Monsoon Region" (JIRCAS, 2025) under the Green Asia project ("Accelerating application of agricultural technologies which enhance production potentials and ensure sustainable food systems in the Asia-

Monsoon region”). The scalable technologies in the catalog are expected to contribute to the establishment of sustainable food systems in the region.

The Technology Catalog was presented at the ASEAN Workshop and Forum associated with the development of the Action Plan for Sustainable Agriculture in ASEAN on May 30 and November 22, 2023, respectively, and subsequently posted on the ASEAN Secretariat website. It has also been featured in the “ASEAN-Japan MIDORI Cooperation Plan for Strengthening Cooperation towards Enhancing Resilient and Sustainable Agriculture and Food Systems for Ensuring Regional Food Security”. The catalog has received considerable attention, with more than 10,000 access and downloads as of March 12, 2026.

However, more research is needed to determine the applicability of these technologies and translate them into tangible solutions for food systems transformation. Currently, there is a gap in knowledge on which technologies are most applicable to different countries or areas in the ASEAN region, as this aspect has not been thoroughly investigated.

This pilot study aims to evaluate the impact of technology adoption and elucidate the constraints and enabling factors for the adoption of two of the promising technologies listed in the catalog: "Mitigation of methane emissions from local cattle using cashew nut shell liquid (CNSL) feeding" and “the pH control technology for maintaining the acidity of fermented rice noodles (FRN)” in the ASEAN countries.

The selection was based on their technological readiness for small, family-based producers in the region. Both technologies are already at the implementation stage, are highly compatible with existing production systems, do not require additional substantial investment or system changes, and demand minimal skill to practice—demonstrating a high level of technology readiness.

The following three specific objectives will be clarified qualitatively and quantitatively regarding the above technologies:

1) To understand the current status associated with technology adoption
2) To estimate enteric methane emission for CNSL and food loss for FRN
3) To explore policy support for mitigation measures and clarify the policy implications for technology dissemination

This pilot study was conducted in Thailand and Vietnam, where the cattle industry is growing due to increasing demand for beef and dairy products. Both countries also have a long-standing tradition of FRN, ensuring stable consumer demand for the product.

With the cooperation of ERIA, JIRCAS has officially reported the outline and progress of the study at the relevant ASEAN Sectoral Working Group. Specifically, the project outline together with the Technology Catalog was introduced at the 18th meeting of ASEAN Technical Working Group on Agricultural Research and Development (ATWGARD) held in April 2024, and the progress and preliminary findings of the project were reported at the 19th meeting of ATWGARD held in May 2025. In the meetings, several AMSs showed their interest in the result of this pilot study.

2: Cashew nutshell liquid feeding

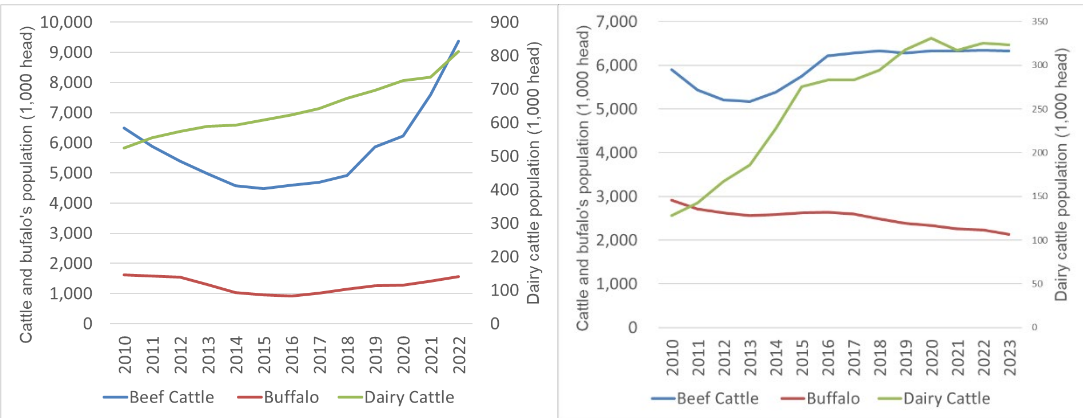
2.1: Target technology description

Livestock farming, particularly the raising of ruminant animals, has been identified as a significant contributor to greenhouse gas (GHG) emissions. Among various strategies for modifying ruminal conditions, CNSL has gained attention due to its bioactive - anacardic acid, cardanol, and which exhibit antibacterial activity against archaea and gram-positive bacteria (Kubo et al., 1993; Shinkai et al., 2012). Several studies have demonstrated the methane-reducing effects of CNSL feeding. An *in vivo* experiment conducted in Florida, USA, using Angus crossbred steers showed that supplementation with cashew nutshell extract reduced methane emissions by 31% in high-grain diets while improving nutrient digestibility and resulting in greater final body weight (Cuervo et al., 2025). Goetz et al. (2023) found that CNSL supplementation positively affected milk and protein yields in transition of dairy Holstein cows in Iowa, USA. In an *in vivo* experiment conducted in Hokkaido, Japan, Holstein non-lactating cows exhibited a 19% reduction in methane production without compromising digestibility (Shinkai et al., 2012).

A study on Lai Sind cattle, the most widespread beef cattle breed in Vietnam, demonstrated a 20-23% reduction in enteric methane emissions with CNSL feeding (Maeda et al., 2021, JIRCAS (2025)). Additionally, CNSL supplementation reduced the abundance of methanogens and increased the population of propionate-producing bacteria in the rumen, improving the production of the cattle (Maeda et al., 2021). These consistent findings in Southeast Asia suggest that CNSL technology has broad applicability for zebu cattle breeds (*Bos indicus*), which are common in the ASEAN region.

2.2: Trends in the cattle industry and beef consumption in selected countries

The number of major ruminant cattle (beef, buffalo, and dairy) has been increasing in Thailand since the mid-2010s. Among these, beef cattle dominate, accounting for 80% of the total, with a sharp recent increase driven by rising consumer demand for beef. In Vietnam, the increase in beef cattle has been more moderate since the mid-2010s, with beef cattle comprising approximately 70% of the total (Fig 1).



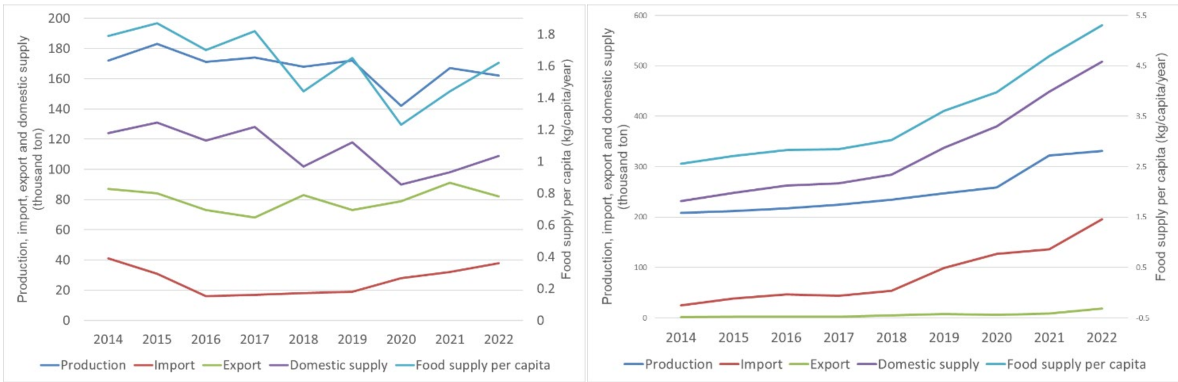
Thailand Vietnam

Fig 1. Cattle and buffalo population in Thailand and Vietnam

Source: Office of Agricultural Economics of Thailand (2024); General Statistics Office of Vietnam (2023a); and various documents.

Per capita beef consumption and exports have fluctuated over the past decade in Thailand but have shown an overall upward trend since 2020. Although beef imports have also risen moderately, their share of total domestic supply remains small, suggesting that domestic production is the primary source of national consumption. It is also noteworthy that Thailand is a net exporter of beef, indicating that the beef industry is expected to continue growing.

In Vietnam, per capita beef consumption is significantly higher than in Thailand and has sharply increased since 2018, recently exceeding 5 kg per person. While beef imports have increased, they remain insufficient to meet rising demand, highlighting the need to promote domestic production to satisfy the growing market (Fig 2).



Thailand Vietnam

Fig 2. Beef production, imports, exports, domestic supply, and food supply per capita in Thailand and Vietnam

Source: FAO (2025)

2.3: Impact assessment of CNSL feeding

For Thailand, to estimate the mitigation potential of CNSL feeding under the assumption of full adoption by beef producers, methane (CH_4) emissions from beef cattle were estimated using the data of the Ministry of Natural Resources and Environment of Thailand (MNRE) (2024) and method developed by the Intergovernmental Panel on Climate Change (IPCC) (2006). This method was also used by MNRE in their report (2024):

- Emissions = EF(T) × N(T)
- Total CH_4 Enteric = Σ(Emissions)

Where:

- Emissions = methane emissions from Enteric Fermentation (kg CH_4/year)
- EF(T) = emission factor for the defined livestock population (kg CH_4/head/year)
- N(T) = the number of head of livestock category
- T: category of livestock
- Total CH_4 Enteric = total methane emissions from enteric fermentation (kg CH_4/year)

The data on the number of livestock heads by category were obtained from Thailand's first Biennial Transparency Report (MNRE, 2024). In this data, the emission factor for female heifers is not provided; therefore, it was estimated as the average of the emission factors for female heifers aged <1 year and >1 year.

Methane (CH_4) reduction through CNSL feeding ranges from 20.2% (low) to 23.4% (high). (Maeda et al., 2021). The calculated results are presented in Table 1 below.

Table 1. Estimation of enteric methane emission from beef cattle in Thailand, 2022

Category			Population (heads)	EF (kg CH_4/head/year)	CH_4 Emissions (kg/year)	CH_4 Emissions ($ktCO_2$-eq/year)	CH_4 reduction by CNSL feeding ($ktCO_2$-eq/yr)	
							Upper	Lower
Native	Male		1,444,928	44.6	64,487,136.6	1805.6	422.5	364.7
	Female	Heifer	1,927,528	33.8*	65,102,258.2	1822.9	426.5	368.2
		From 1st pregnancy	1,528,255	47.2	72,103,070.9	2018.9	472.4	407.8
Pure/ crossed breed	Male		1,031,405	65.0	67,000,068.8	1876.0	439.0	379.0
	Female	Heifer	1,536,385	50.8	78,079,085.7	2186.2	511.6	441.6
		From 1st pregnancy	1,630,371	62.0	101,115,609.4	2831.2	662.5	571.9
	Fattening		295,239	55.7	16,450,717.1	460.6	107.8	93.0
Total			9,394,111		464,337,946.7	13001.5	3,042.3	2,626.3

Source: author's calculation using the data and method of Thailand Ministry of Natural Resources and Environment (MNRE) (2024) (following IPCC 2006 Guidelines)
Reduction by CNSL feeding: reduction ranges from 20.2% (Low) to 23.4% (High) (Maeda et al 2021).
*These are the average emission factors for heifers aged less than 1 year and over 1 year

For Vietnam, since the beef cattle data were not disaggregated by breed and age group, emissions from beef cattle were estimated using the method developed by Tee et al. (2022):

- CH_4 (g/kg DMI) = 34.32+19.81DMI-0.43NDF
- DMI (kg) = 0.0182BW
- NDF (kg) = 0.0089BW

Where:

- DMI: Dry Matter Intake
- NDF: Neutral Detergent Fiber
- BW: Body Weight

CNSL feeding is assumed to begin at weaning (body weight of 50 kg) and continue until shipping (350-450 kg)(Nguyen et al., 2022). The number of beef cattle is assumed to be evenly distributed across body weight classes. The number of cattle in the 0-49 kg weight class is estimated to account for 11.2% of the total population. The remaining cattle are assumed to be evenly distributed, with 11.1% allocated to each of the 50-450 kg weight classes. The calculated results are presented in Table 2 below.

It should be noted that the method of Tee et al. (2022) could not be applied for the case of Thailand due to lacking data on the number of beef cattle prior to weaning (0-49 kg) which can affect the accuracy of emission estimates.

Table 2. Estimation of enteric methane emission from beef cattle in Vietnam, 2022

Body weight (kg/head)	Body weight median (kg/head)	Number of beef cattle (head)	DMI/head (kg/day)	NDF/head (kg/day)	CH_4 emission (g/day/head)	Total CH_4 emission (t/day)	CO_2 Equivalent (kt/year)	CH_4 reduction by CNSL feeding ($ktCO_2$-eq/year) High	Low
0-49	25	663,260	NA	NA	NA	NA	NA	NA	NA
50-99	75	657,338	1.4	0.7	61.1	40.1	410.3	NA	NA
100-149	125	657,338	2.3	1.1	78.9	51.9	530.1	124.0	107.1
150-199	175	657,338	3.2	1.6	96.7	63.6	649.9	152.1	131.3
200-249	225	657,338	4.1	2.0	114.6	75.3	769.8	180.1	155.5
250-299	275	657,338	5.0	2.4	132.4	87.0	889.6	208.2	179.7
300-349	325	657,338	5.9	2.9	150.3	98.8	1,009.4	236.2	203.9
350-399	375	657,338	6.8	3.3	168.1	110.5	1,129.2	264.2	228.1
400-450	425	657,338	7.7	3.8	185.9	122.2	1,249.0	292.3	252.3
Total	-	5,921,963	-	-	-	649.4	6,637.3	1,457.1	1,257.9

Source: author's calculation using the data of General Statistics Office of Vietnam (2023) and method of Tee et al. (2022). Total of number of beef cattle may not equal the sum of components due to rounding.

The agricultural sector accounts for 25% and 15% of total national GHG emissions in Thailand and Vietnam, respectively. Within the agricultural sector, enteric fermentation contributes to 27% of emissions in Thailand and 18% in Vietnam. CNSL feeding has the potential to reduce enteric methane emissions from beef cattle by 20-23% in Thailand and 19-22% in Vietnam. Furthermore, it is estimated that feeding CNSL to beef cattle could reduce total enteric methane emissions by 14–17% in Thailand and 10–11% in Vietnam (Table 3). If CNSL can also be applied to dairy cattle, whose numbers have been increasing in recent years, these reduction levels are expected to increase further.

Although no conclusive evidence is available to fully explain the difference in mitigation potential between the two countries, this discrepancy may partly result from differences in the estimation methods employed. In the case of Thailand, the IPCC 2006 Tier 2 methodology was used, with emission factors calculated by cattle breed and age group based on relatively detailed livestock data. However, a major limitation of this approach is that it does not explicitly account for body-weight-dependent variables, particularly for beef cattle prior to weaning, which can influence emission estimates.

In contrast, owing to the limited availability of disaggregated data in Vietnam, specifically the lack of data by breed and age group, the method proposed by Tee et al. (2022) was applied. For the caculation, besides the observed data on the number of beef cattle prior to weaning, the remaining cattle population was assumed to be evenly distributed across eight body weight classes, and the potential reduction in enteric methane emissions was estimated as a function of body weight, with CNSL supplementation assumed to begin at weaning.

To reduce uncertainties associated with these methodological differences, future research in Thailand would benefit from the collection of data on the number of beef cattle prior to weaning by breed. In Vietnam, the availability of more detailed livestock data by breed and age group would facilitate the application of more refined and robust estimation approaches.

Table 3. GHG emissions by sector, enteric fermentation, and reduction effects of CNSL feeding in beef cattle ($ktCO_2$-eq/yr) in Thailand and Vietnam

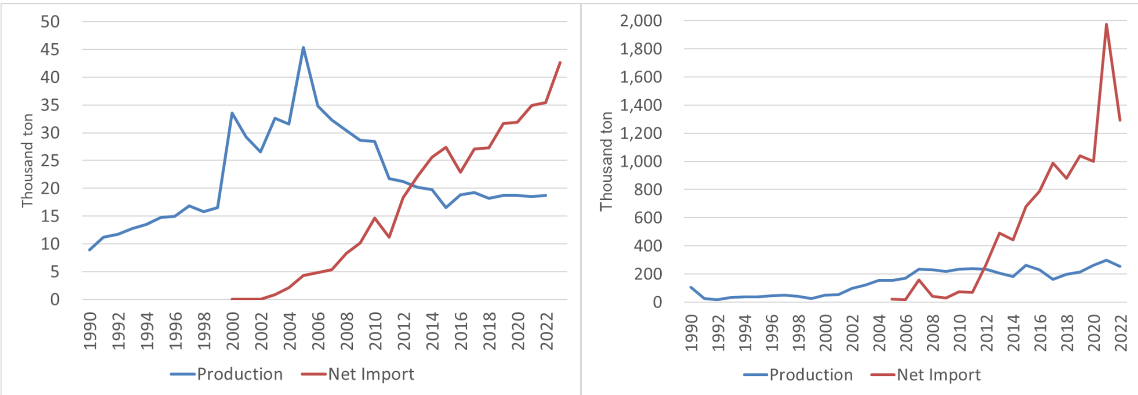
	All sectors (A)	Agriculture (B)	Total enteric fermentation (C)	Enteric fermentation from beef cattle (D)	CH_4 reduction by CNSL feeding to beef cattle (E)	
					High estimation	Low estimation
Thailand 2022	278,040 [a]	68,934[a]	18,347 [a]	13,001 [c]	3,042 [c]	2,626 [c]
		24.8 [d]	6.6 [e]	4.7 [g]	1.1 [j]	0.9 [j]
			26.6 [f]	18.9 [h]	4.4 [k]	3.8 [k]
				70.9 [i]	16.6 [l]	14.3 [l]
					23.4 [m]	20.2 [m]
Vietnam 2022	475,144 [b]	72997 [b]	13,084 [b]	6,637 [b]	1,457 [c]	1,258 [c]
		15.4 [d]	2.8 [e]	1.4 [g]	0.3 [j]	0.3 [j]
			17.9 [f]	9.1 [h]	2.0 [k]	1.7 [k]
				50.7 [i]	11.1 [l]	9.6 [l]
					22.0 [m]	19.0 [m]

[a] MNRE (2024)
[b] Author's calculation based on FAO data, adjusted to IPCC categories. See Supplemental Table 1 for details.
[c] Author's calculation.
[d] B/A%, [e] C/A%, [f] C/B%, [g] D/A, [h] D/B, [i] D/C , [j] E/A, [k] E/B, [l] E/C, [m] E/D

2.4: Supply potential of cashew nutshell

CNSL is a dark reddish-brown caustic liquid rich in non-isoprenoid phenolic lipids, extracted from cashew nut shells, a byproduct of cashew nut processing (Mgaya et al., 2019). Cashew nut shells are often discarded as waste, posing environmental concerns in various countries (Mgaya et al., 2019). The cashew tree (*Anacardium occidentale*) is widely cultivated in tropical regions between 25°N and 25°S, including Africa, South America, and South and Southeast Asia. It is well-adapted to hot, dry areas where intensive crop production is unsuitable.

The supply potential of cashew nut shells, the raw material for CNSL, is estimated using a shell-to-whole-nut conversion ratio of 0.75 (Ministry of Agriculture and Rural Development and Ministry of Science and Technology Vietnam, 2018). Thailand was once a major cashew producer, but production has declined over the past 20 years, stagnating at approximately 19,000 tons, while net imports have increased in parallel. As a result, Thailand's total cashew shell supply potential was 48,000 tons in 2022. In contrast, Vietnam has a much higher supply potential due to a sharp increase in net imports, despite domestic production ranging between 200,000 and 300,000 tons. By 2022, Vietnam's total supply potential had reached 2 million tons (Fig 3).



Thailand Vietnam

Note: Calculated from production, import, and export data of cashew nuts in shell, using the formula: Cashew nutshell = Cashew nut in shell × 0.75

The conversion ratio is based on the Ministry of Agriculture and Rural Development and Ministry of Science and Technology Vietnam (2018), TCVN 12380:2018

Fig 3. Supply potential of cashew nut shells in Thailand and Vietnam

Source: FAO (2025)

Planting areas in Thailand closely align with the distribution of the beef cattle population, suggesting favorable conditions for establishing CNSL processing plants (Fig 4). In Vietnam, beef cattle are widely distributed throughout the country, while cashew nut production is concentrated in the mid-southern provinces (Fig 5). Considering the high potential for various processed products derived from cashew nut shells (Mgaya et al., 2019) and the demand from the manufacturing sector, the northern region of Vietnam could also be a suitable location for CNSL processing plants.

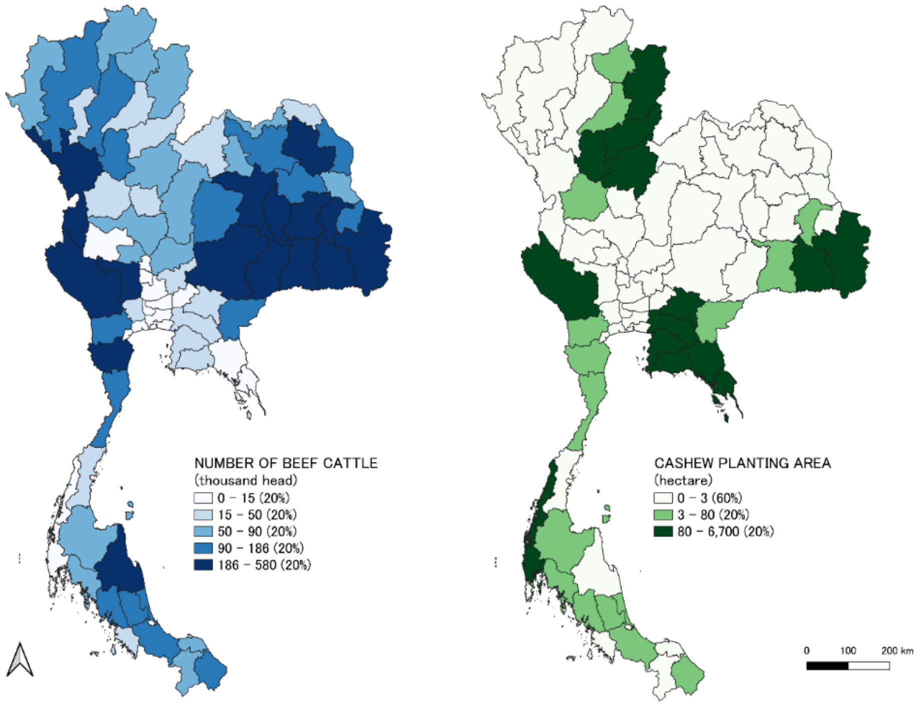
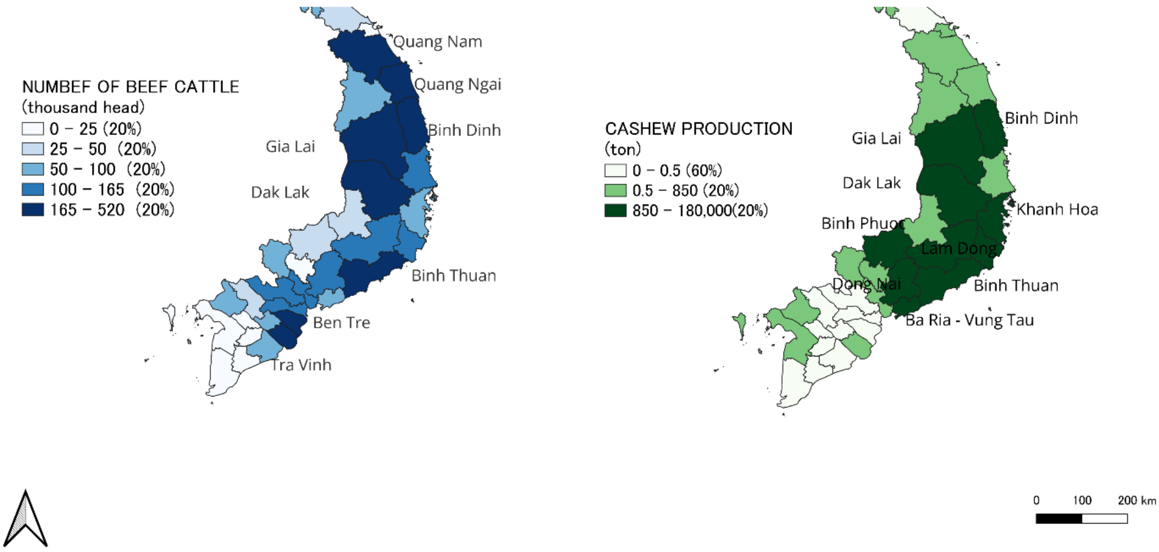


Fig 4. Distribution of beef and cashew planting areas in Thailand (2022)

Source: Office of Agricultural Economics of Thailand (2024), Agricultural statistics of Thailand (2023)

The overlap between cashew production areas and agriculturally disadvantaged regions suggests that promoting industries that utilize currently discarded cashew by-products could contribute to poverty alleviation and regional development.



Note: The map includes provinces from the South Central Coast to Southern regions of Vietnam. All boundaries correspond to the administrative divisions in effect before the 2025 provincial consolidation decision

Fig 5. Distribution of beef and cashew production in Vietnam (2022)

Source: Beef cattle data: General Statistics Office of Vietnam (2023a)
Cashew production data: General Statistics Office of Vietnam (2023b)

2.5: Policy recommendations

The research results indicate that both Vietnam and Thailand have recently increased beef consumption and cattle farming, leading to greater pressure on greenhouse gas emissions. Feeding cattle with CNSL could help reduce enteric methane emissions from beef cattle by 20–23% in Thailand and 19–22% in Vietnam. Both countries have domestic sources of cashew nutshell liquid available for use in the livestock sector. However, to facilitate widespread adoption, supportive policies are necessary. CNSL compound feed is not yet commercially available in ASEAN countries, requiring government approval as a safe feed and the establishment of a supply chain by the private sector. In 2025, Thailand Taxonomy for agricultural sector was published, which includes CNSL as one of the elements of eligible practices for sustainable livestock production (Thailand Taxonomy Board, 2025). To further incentivize its use, implementing a carbon credit scheme could provide farmers with tangible economic benefits.

From a data collection perspective, ensuring consistency in estimates of the potential to reduce enteric methane emissions from beef cattle between countries will require greater emphasis on the collection of detailed information. In the case of Vietnam, more data on cattle breeds and age structures needs to be collected.

3: Maintaining an acidic condition to prevent the liquefaction of fermented rice noodles (FRN)

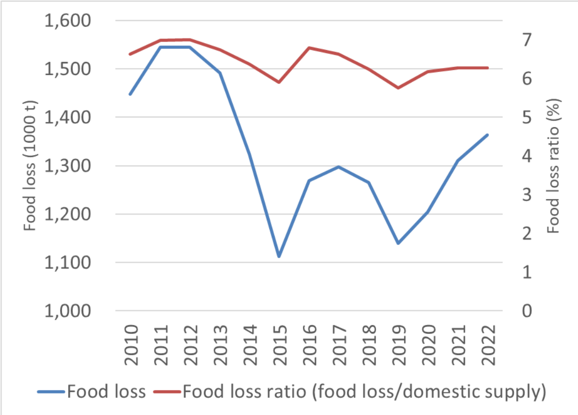
3.1: Target technology description

Fermented rice noodles (FRN) are a traditional food that is broadly produced and consumed across Thailand, Vietnam, Laos, Cambodia, Myanmar, and China. Traditionally, FRN manufacturing is dominated by small-scale family operations that employ a few temporary workers and are typically located near residential areas. The FRN products are characteristically acidic, with a pH value of approximately 4, as they are made from fermented rice flour that contains lactic acid generated during the fermentation process. Thus, they generally remain edible and maintain their characteristic texture and flavor for a few days at tropical ambient temperatures (Marui et al., 2020). However, liquefaction can occur unpredictably within a day at either the production or retail site, causing significant economic losses (Kusano et al., 2021; Marui et al., 2020). Liquefaction is attributed to bacterial amylolytic enzymes, which become active when the pH rises to 6 or higher. It can be prevented by maintaining an acidic condition of approximately pH 4 (Marui et al., 2020, JIRCAS 2024). The cost of monitoring and managing pH levels and/or lactic acid content in noodles and fermented rice flour is lower than that of using common food preservatives (Kusano et al., 2021).

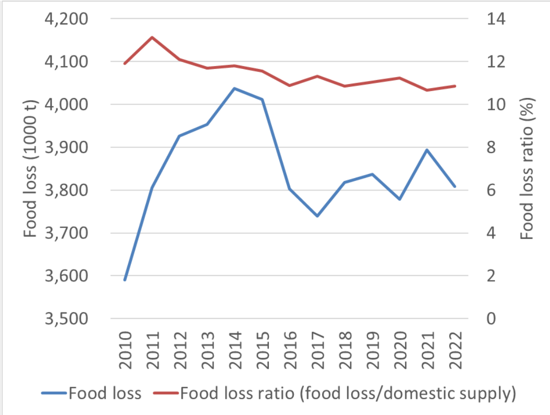
3.2: Overview of rice product losses and FRN consumption in selected countries

Rice and rice products are staple foods in many Asian countries. In Thailand, they accounted for 42% of per capita daily calorie intake in 2022 (FAO, 2025). In Vietnam, cereals provide half of the daily energy intake, with rice contributing 83% of total cereal consumption and 44% of total daily calorie intake (Martius et al., 2023)

Food loss from rice and rice products in Thailand has sharply increased since 2019, reaching 1.4 thousand tons in 2022. However, its proportion relative to domestic supply has remained stable at 6-7% between 2010 and 2020. In Vietnam, food loss has fluctuated between 3.7 and 3.9 thousand tons since 2017, with its ratio over domestic supply remaining at approximately 11% (Fig 6). However, actual food loss may be lower than these estimates, as some degraded food products are repurposed as animal or fish feed or recycled as compost, though accurate data on these practices are lacking.



Thailand



Vietnam

Fig 6. Food loss of rice and rice products in Thailand and Vietnam

Source: FAO (2025)

FRN have long been consumed and are deeply embedded in the national diets of China and Southeast Asian countries. In Thailand, the FRN product known in Thai as *Khanom Jeen* consistently accounts for approximately 5% of total rice and rice product consumption (Table 4). It is regularly eaten at home and in restaurants for breakfast, lunch, and dinner. Consumption patterns among young and middle-aged generations are nearly identical, suggesting that demand is likely to remain stable in the future.

Table 4. Rice and rice product consumption in-house and eat-out, Thailand (g/person/day, age >= 3)

Food group (cooked)	2002-05 (a)	2013-15 (b)	b/a ratio	Polished rice equivalent (2013-15)
Steamed rice	345.2 (77.3)*	343.3 (84.4)	0.99	141.1 (91.0)
Congee	25.3 (5.7)	25.3 (6.2)	1.00	2.7 (1.7)
Khanom Jeen (fermented rice noodles)	21.7 (4.9)	19.9 (4.9)	0.92	5.4 (3.5)
Senyai, Senlek, Senmee, etc. (fresh and instant noodles)	19.2 (4.3)	13.2 (3.2)	0.69	5.8 (3.7)
Others	7.0 (1.6)	NA	NA	NA
Total	446.6	406.6	0.91	155

*Figures in parentheses indicate the percentage (%) of each food group relative to the total consumption.
Source: Ministry of Agriculture and Cooperative of Thailand (2015). Database of Food Consumption of Thai People 2013-2015
2002-05 data derived and modified from Kusano (2017)

In Vietnam, while in-house rice consumption has been gradually declining, rice noodle consumption has remained stable, with its share of total rice and rice product consumption showing a slight increase (Table 5). Similar to Thai *khanom Jeen,* the Vietnamese FRN product commonly known as *bun* is a well-established dish in Vietnam, widely available in restaurants in both urban and rural areas.

Table 5. In-house consumption of rice and rice products in Vietnam (kg/year/person)

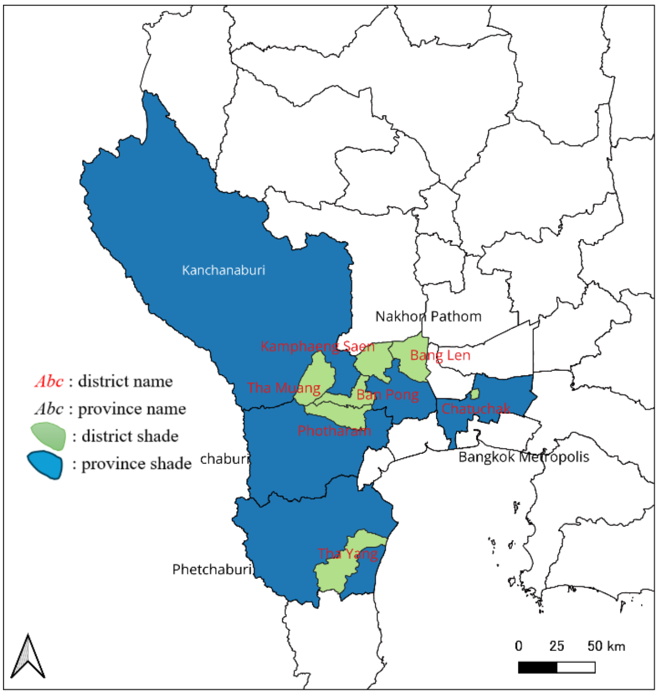
Food group	2010 (a)	2020 (b)	b/a
Plain rice (uncooked)	119.9 (90.0)*	96.1 (88.7)*	0.80
Sticky rice (uncooked)	5.1 (3.8)	3.5 (3.3)	0.69
Instant noodle/porridge	4.4 (3.3)	4.9 (4.5)	1.11
Pho, Bun (fermented rice noodles), dried rice noodles	3.4 (2.5)	3.3 (3.1)	0.97
Vermicelli	0.5 (0.4)	0.5 (0.5)	1.00
Total	133.2 (100)	108.4 (100)	0.81

* Figures in parentheses indicate the percentage (%) of each food group relative to total consumption.
Source: General Statistic Office of Vietnam (2010, 2020). Vietnam Household Living Standard Survey 2010 and 2020.

3.3: Impact assessment of FRN technology

3.3.1: Description of interview surveys with FRN manufacturers and retailers

A semi-structured interview survey was conducted with typical noodle producers and retailers (n = 5 for each group) to assess the general production and sales operations, as well as liquefaction-related losses in the provinces of Bangkok, Kanchanaburi, Nakhon Pathom, Phetchaburi, and Ratchaburi in Thailand (December 2024), and Hanoi capital in Vietnam (September 2024) (Fig 7a, 7b).

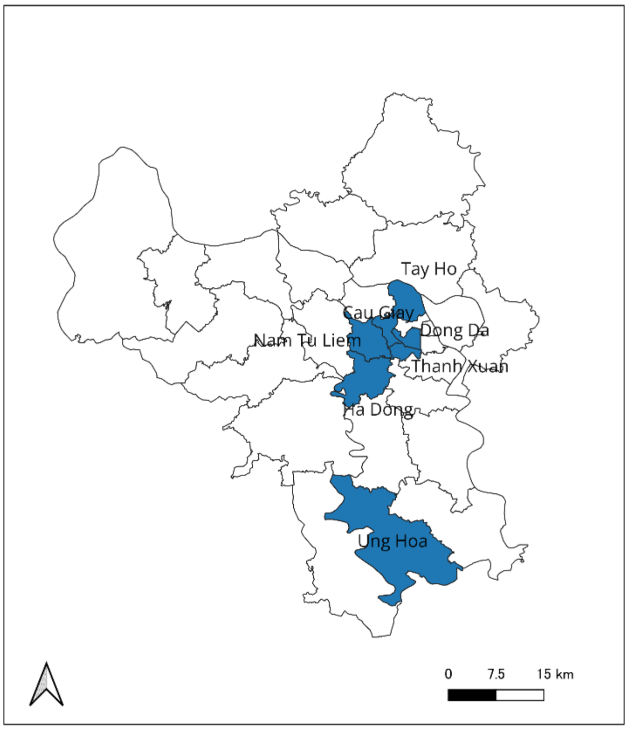


Number of survey sample by Province and District, Thailand, December 2024

Province	District	Manufacturer	Retailer	Total
Bangkok	Chatuchak	0	1	1
Kanchanaburi	Tha Maung	1	1	2
Nakhon Pathom	Bang Len	0	1	1
	Kamphaeng Saen	1	0	1
Phetchaburi	Tha Yang	1	1	2
Ratchaburi	Ban Pong	1	0	1
	Photharam	1	1	2
Total		5	5	10

Source: Authors

Fig 7a. Locations of interview survey in Thailand (December 2024)
Source: survey data



Number of survey samples by district, Hanoi, Vietnam, September 2024

District	Manufacturer	Retailer	Total
Cau Giay	0	1	1
Dong Da	0	1	1
Ha Dong	1	1	2
Nam Tu Liem	2	0	2
Tay Ho	0	1	1
Thanh Xuan	0	1	1
Ung Hoa	2	0	2
Total	5	5	10

Source: Authors

Fig 7b. Locations of the interview survey in Vietnam (December 2024)

Source: survey data

Fig 8a. A noodle factory in Thailand

Fig 8b. A noodle factory in Vietnam

In Thailand, noodle factories operate for around nine hours a day, from 5:00-8:00 until 11:00-17:00, delivering products to retailers and small local restaurants within the same day. Delivery takes place 1-3 hours after production. If there are leftovers, they are stored at room temperature for the next day (Table 6a). The quality of the noodles remains unchanged when stored at room temperature for a day. The factory operates almost year-round, with some seasonal fluctuations, producing between 150,000 (P2) and 400,000 (P5) tons annually (Table 7a).

In Vietnam, production begins at 1:00-2:00 and ends at 16:00-17:00, running for 15 hours daily with two delivery rounds within 1-5 hours after production. Unsold products are rarely stored, as retailers and consumers do not accept products older than one day (Table 6b). Similar to Thailand, Vietnamese factories operate year-round, with only a single day off for New Year's Day, producing between 150,000 (VP2) and 650,000 (VP3) tons annually (Table 7b).

Table 6a. Work operations in fermented rice noodle production, Thailand

Sample #	Daily operation						Delivery frequency (times/day)	Product storage at factory (days)
	Working hours			Delivery time after production (hr)				
	Start time	Close time	Work hours	Normal	Shortest	Longest		
TP1	8:00	17:00	9:00	3:00	1:00	3:00	1	1
TP2	5:00 (4:00)*	11:00 (17:00)*	6:00 (13:00)*	2:00	1:00	6:00	1	1
TP3	8:00	17:00	9:00	1:30	0:45	2:00	1	1
TP4	5:00	14:00	9:00	1:00	1:00	1:30	2	1
TP5	8:00	17:00	9:00	1:30	1:00	2:00	1	1
Average	6:20	15:30	9:10	1:48	0:57	2:54	1.2	1
SD	1:51	2:30	2:13	0:45	0:06	1:49	0.4	0

*Values in parentheses indicate figures during busy periods.
Source: Survey data

Table 6b. Work operations in fermented rice noodle production, Vietnam

Sample #	Working hours			Delivery time after production (hr)			Delivery frequency (times/day)	Storage at factory (days)
	Start time	Close time	Work hours	Normal	Shortest	Longest		
VP1	2:00	16:30	14:30	2:00	0:30	4:00	2	0
VP2	2:00	16:00	14:00	2:00	1:00	4:00	2	0
VP3	2:00	16:30	14:30	2:00	1:00	4:00	2	0
VP4	1:00	16:30	15:30	1:00	0:30	2:00	2	0
VP5	1:00	17:00	16:00	4:00	1:00	12:00	2	1
Average	1:36	16:30	14:54	2:12	0:48	5:12	2.0	0.2
SD	0:32	0:21	0:49	1:05	0:16	3:53	0.0	0.4

Source: Survey data

Table 7a. Production volume of fermented rice noodles by operation intensity, Thailand

Operation intensity	Normal period		High period		Low period		Total	
Sample #	Days	Production (kg/day)	Days	Production (kg/day)	Days	Production (kg/day)	Days	Production (kg/year)
P1	248	150	95	400	20	100	363	182,720
P2	147	160	88	400	128	90	363	151,300
P3	250	280	95	700	20	180	365	300,500
P4	155	450	90	600	120	360	365	194,775
P5	258	380	90	800	15	200	363	401,700
Average	211.6	284.0	91.6	580.0	60.6	186.0	363.8	246,199.0
SD	55.5	132.4	3.2	178.9	58.0	108.5	1.1	103,451.7

Source: Survey data

Table 7b. Production volume of fermented rice noodles by operation intensity, Vietnam (2024)

Sample #	Operation intensity			Annual operation days (b)	Annual production (kg/year) (a × b)
	Normal (kg/day) (a)	High (kg/day)	Low (kg/day)		
VP1	1,250	1,300	1,200	364	455,000
VP2	425	500	350	364	154,700
VP3	1,800	2,000	1,600	364	655,200
VP4	600	700	500	364	218,400
VP5	500	NA	NA	364	182,000
Average	915.0	1125.0	912.5	364.0	333,060
SD	593.1	675.2	589.3	0.0	215,883

Source: Survey data

Corresponding to manufacturing, retail is operating almost year-round in Thailand and Vietnam. Daily trade amount ranges 58kg to 276kg, resulting in 62 thousand tons yearly in Thailand in average (Table 8a). In Vietnam, operation is also year-round and daily trade amount of 125kg to 500 kg, resulting in 89 thousand tons a year (Table 8b).

Fig 9a. Retailer in Thailand

Fig 9b. Retailer in Vietnam

Table 8a. Retail operation and trade volume of fermented rice noodles, Thailand

Operation intensity	Normal period		High period		Low period		Total	
Sample #	Days	Sale (kg/day)	Days	Sale (kg/day)	Days	Sale (kg/day)	Days	Sale (kg/year)
S1	289	75	36	140	30	50	355	28,215
S2	255	100	90	400	20	55	365	62,600
S3	NA	30	104	40	NA	15	NA	NA
S4	155	150	90	300	120	90	365	61,050
S5	258	190	90	500	15	80	363	95,220
Average	239.3	109.0	82.0	276.0	46.3	58.0	362.0	61,771.3
SD	58.2	62.7	26.4	187.3	49.6	29.3	4.8	27,362.1

Source: Survey data

Table 8b. Retail operation and trade volume of fermented rice noodles, Vietnam

Sample #	Daily sale (kg/day)	Median of daily sale (kg/day) (a)	Annual operation days (b)	Annual sale (kg/year) (a × b)
VS1	200～300	250	364	91,000
VS2	200～250	225	364	81,900
VS3	120～130	125	364	45,500
VS4	500	500	364	182,000
VS5	100～150	125	340	42,500
Average	-	245.0	359.2	88,580.0
SD	-	153.5	10.7	56,473.5

Source: Survey data

All the manufacturers and retailers interviewed had experienced liquefaction of the noodles products they handled. In Thailand, liquefaction occurs 1-6 times per year, lasting for 2-14 days each time, affecting 10-100% of daily production. When liquefaction occurs, producers replace the damaged products at no cost. In Vietnam, the manufacturers had experienced liquefaction daily, with 10% of products being affected (Table 9a, 9b).

In Thailand, retailers encounter the liquefaction problem 1-3 times per year, lasting 2-7 days, and losing 2-33% of daily sales. They are eager to adopt the technology to ensure or extent product shelf life as a way to build consumer trust. In Vietnam, all unsold products at the end of the day are discarded, resulting in an 18% loss of daily sales. Retailers also support technology to meet consumer demand for high-quality, safe products and to expand sales opportunities to supermarkets. However, there are concerns about changing eating habits, ensuring that no chemicals are used, and obtaining government approval to enhance consumer confidence (Table 10a, 10b).

Table 9a. Liquefaction of fermented rice noodles at factories, Thailand

Sample #	Frequency (time/yr)	Season	Duration (days)	Daily production damage ratio (%)	Claim response
TP1	1	Summer*	7	100	Replaced free of charge
TP2	4～6	Summer/Seasonal change	14	30	Replaced free of charge
TP3	1	Summer	2	10	Replaced free of charge
TP4	2～3	Summer	7	20	Replaced free of charge
TP5	2	Summer	7	20	Replaced free of charge
Average	2.7	-	7.4	36	-
SD	1.8	-	4.3	36.5	-

* March-July
Source: Survey data

Table 9b. Liquefaction of fermented rice noodles at factories, Vietnam

Sample #	Experience	Frequency	Daily production damage ratio (%)
VP1	Yes	Every day	10
VP2	Yes	DK	DK
VP3	Yes	Every day	10
VP4	Yes	Every day	10
VP5	Yes	DK	DK

Source: Survey data

Table 10a. Liquefaction damage of fermented rice noodles at retail, Thailand

Sample #	Frequency (times /year)	Duration (days)	Daily sales damage ratio (%)	Consumer claims (times/year)	Benefit of shelf-life extension (1-2 days)*
TS1	1	7	20	1	Gain consumer trust
TS2	2～3	3	2	1	Gain consumer trust
TS3	DK	DK	7	DK	DK
TS4	2～3	7	33	2	Gain consumer trust
TS5	1	2	11	2	Gain consumer trust
Avg	2	4.8	14.4	1.5	-
SD	0.9	2.6	12.6	0.6	-

*Multiple-choice options: Increase profit, reduce work hours, reduce purchase frequency, Gain consumer trust.
Source: Survey data

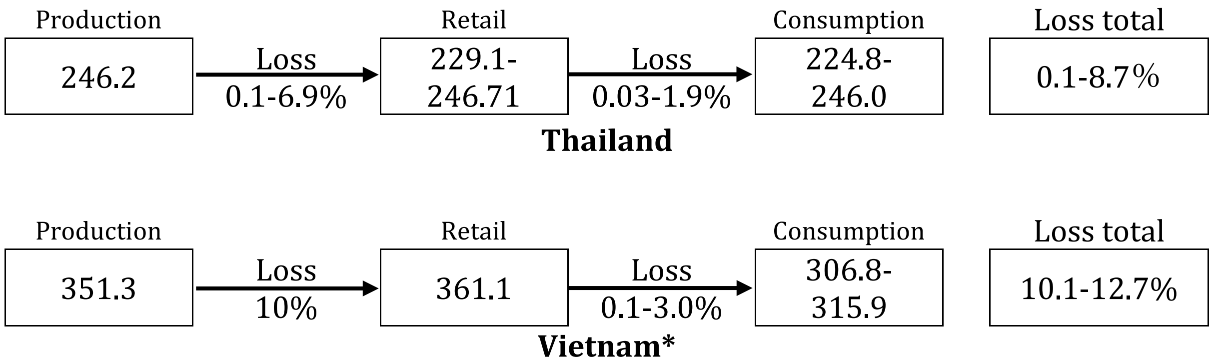
Table 10b. Liquefaction damage of fermented rice noodles at retail, Vietnam

Sample #	Frequency* (times/month)	Daily sales damage ratio (%)	Opinion on noodle shelf-life extension**
VS1	15	6	Welcomed, as demand for quality and safer products is increasing.
VS2	2	2.2	Eating fresh noodles daily is an ingrained habit and difficult to change.
VS3	6	8	NA
VS4	2	1	Willing to sell long shelf-life noodles to supermarkets but require government authorization.
VS5	DK	-	Willing to sell long shelf-life noodles but need to explain to consumers that no chemicals are used.
Average	6.3	4.3	-
SD	6.1	3.3	-

*Frequency refers to the occurrence of unsold noodles in a day. Unsold noodles are not stored for sale the next day.
**Open-ended question
Source: Survey data

3.3.2: Estimating food loss due to liquefaction of FRN

At the micro level, the flow of FRN from manufacturers to consumers and eateries is summarized in Fig 10. In Thailand, 0.1-6.9% of annual production is affected by liquefaction at the production stage, while in Vietnam, 10% is impacted. At the retail stage, 0.03-1.9% of noodles are lost in Thailand and 0.1-3.0% in Vietnam.



*Loss includes unsold noodles within a day.
Source: Survey data

Fig 10. Estimating food loss due to liquefaction of FRN

It is important to note the limitations of this estimation that underreporting of negative information may result in an underestimation of liquefaction damage. Both manufacturers and retailers' welcome technologies that extend shelf life, expecting reduced food loss, economic benefits, lower workload, and increased consumer trust.

3.4: Policy recommendations

The research results indicate that food loss from rice and rice products in Thailand and Vietnam is relatively high. Among rice-based products, fermented rice noodles (FRN) have shown relatively stable consumption in recent years. Therefore, reducing food loss in FRN plays an important role in achieving Sustainable Development Goal 12 (responsible consumption and production).

The technology to maintain an acidic condition to prevent the liquefaction of FRN is largely supported by factories and retailers.

Since pH control plays a critical role in both fermented rice flour and noodle production, knowledge sharing with industry stakeholders on the liquefaction mechanism through government agencies, research institutions, and media is crucial for ensuring proper implementation. Furthermore, support from the government and public sector is needed to develop technical guidelines for preventing liquefaction of fermented rice noodles.

4: Conclusion

The results of this pilot study show that the technology for mitigating methane emissions from local cattle through CNSL feeding could reduce enteric methane emissions from beef cattle by 20–23% in Thailand and 19–22% in Vietnam. It is also estimated that feeding CNSL could reduce enteric methane emissions from total enteric fermentation by 14–17% in Thailand and 10–11% in Vietnam. Meanwhile, the technology for maintaining an acidic condition to prevent the liquefaction of FRN could reduce food loss by 0.1–8.7% in Thailand and 10.1–12.7% in Vietnam, respectively. These findings demonstrate that these scalable technologies demonstrate that they have high potential to contribute to the mitigation of GHG emissions and the reduction of food loss in the FRN in the two countries.

The "Technology Catalog Contributing to Production Potential and Sustainability in the Asia-Monsoon region Ver. 4.0" includes 44 scalable technologies designed to enhance production potential and ensure sustainable food systems in the region. The preliminary results conducted in this survey implies that other technologies also have a potential for application, particularly in supporting climate change mitigation and promoting sustainable development in the Asia-Moonsoon region.

Through these activities, we hope that these technologies will make a substantial contribution to the transformation of sustainable food systems in the Asia-Monsoon region. By integrating these innovative solutions into existing agricultural practices, it is expected that the region can move toward achieving multiple Sustainable Development Goals, including those related to responsible consumption and production, climate action, and zero hunger. Continued collaboration among governments, research institutions, the private sector, and local communities will be essential to ensure that these technologies are effectively implemented and bring tangible benefits to farmers and society at large.

Author contribution statement

S.Y conducted survey, compiled the survey results, and drafted initial manuscript. Y.F. conceived the presented idea, compiled the data, and edited the manuscript for finalization. K.M and J.M contributed to the review and editing of the manuscript. M.K contributed to drafting the document, particularly the introduction and provided input from the perspective of the overall regional context of ASEAN.

Acknowledgement

This report was based on a study conducted under the project "Accelerating application of agricultural technologies which enhance production potentials and ensure sustainable food systems in the Asia-Monsoon region", which has been financially supported by the Ministry of Agriculture, Forestry and Fisheries. The authors are especially grateful for the following:

The members of the International Scientific Advisory Board for Strategy "MIDORI" for their valuable comments and guidance on the manuscript. Dr. Eiichi Kusano, Senior Researcher, Social Sciences Division of JIRCAS, Dr. Tomoyuki Kawashima, Professor Emeritus, Department of Animal and Grassland Science, University of Miyazaki, and Dr. Kentaro Yamada, former Policy Fellow, Economic Research Institute for ASEAN and East Asia (ERIA) for providing valuable comments on the survey results. Dr. Norihito Kanamori, Representative, Southeast Asia Liaison Office, JIRCAS for arranging the meeting with Kasetsart University in Thailand. Dr. Nguyen Thi Chau, CEO of Scientists & Coffee Joint Stock Company for assistance in organizing the survey in Hanoi, Vietnam. Dr. Sirinan Shompoosang and Ms. Patthinan Varichanan in Institute of Food Resarch and Product development, Kasetsart University for organizing the survey in Thailand. Ms. Dang Thi Bich Thao, Research Assistant, Social Sciences Division, JIRCAS, for assistance in organizing the data, formatting the report, and creating the visual materials.

Reference

Agricultural statistics of Thailand (2023).

ASEAN. (2022a). *ASEAN regional guidelines for promoting climate-smart agriculture (CSA) practices volume 3*. ASEAN Secretariat.

ASEAN. (2022b). *ASEAN regional guidelines for sustainable agriculture in ASEAN*. ASEAN Secretariat.

Cuervo, W., Gomez, C., Tarnonsky, F., Fernandez-Marenchino, I., Podversich, F., Maderal, A., Schulmeister, T. M., Vargas, J. de J., & DiLorenzo, N. (2025). Effects of cashew nutshell extract inclusion into a high-grain finishing diet on methane emissions, nutrient digestibility, and ruminal fermentation in beef steers. *Journal of Animal Science*, *103*. https://doi.org/10.1093/jas/skae359

FAO. (2023, October). *FAOSTAT domain emissions totals*. https://files-faostat.fao.org/production/GT/GT_en.pdf

FAO. (2025). *FAOSTAT: food balance sheets*. https://www.fao.org/faostat/en/#data/FBS

General Statistic Office of Vietnam. (2010). *Vietnam household living standard survey 2010*.

General Statistic Office of Vietnam. (2020). *Vietnam household living standard survey 2020*.

General Statistics Office of Vietnam. (2023a). *Agriculture, forestry and fishery data*. https://www.gso.gov.vn/en/agriculture-forestry-and-fishery/

General Statistics Office of Vietnam. (2023b). *Vietnam cashew production by province 2022*.

Goetz, B. M., Horst, E. A., Mayorga, E. J., Abeyta, M. A., Rodriguez-Jimenez, S., Carta, S., Lourenco, J. M., Callaway, T. R., Hikita, C., Watanabe, T., & Baumgard, L. H. (2023). Effects of cashew nut shell extract supplementation on production, rumen fermentation, metabolism, and inflammatory biomarkers in transition dairy cows. *Journal of Dairy Science*, *106*(12), 9843–9854. https://doi.org/10.3168/jds.2023-23563

JIRCAS. (2025). *Technology catalog contributing to production potential and sustainability in the Asia-monsoon region ver. 4.0*. https://www.jircas.go.jp/en/greenasia/techcatalog

Kubo, Isao., Muroi, Hisae., Himejima, Masaki., Yamagiwa, Yoshiro., Mera, Hiroyuki., Tokushima, Kimihiro., Ohta, Shigeo., & Kamikawa, Tadao. (1993). Structure-antibacterial activity relationships of anacardic acids. *Journal of Agricultural and Food Chemistry*, *41*(6), 1016–1019. https://doi.org/10.1021/jf00030a036

Kusano, E. (2017). Export and production of rice noodles in Thailand. *Journal of Agricultural Development Studies*, *28*(2), 32–38.

Kusano, E., Marui, J., & Yoshihashi, T. (2021). Basic quality management for improving the business stability of small food enterprises in Southeast Asia: the case of a fermented rice noodle company in Thailand preventing noodle liquefaction. *Japan Agricultural Research Quarterly (JARQ)*, *55*(3), 253–264. https://www.jircas.go.jp

Maeda, K., Nguyen, V. T., Suzuki, T., Yamada, K., Kudo, K., Hikita, C., Le, V. P., Nguyen, M. C., & Yoshida, N. (2021). Network analysis and functional estimation of the microbiome reveal the effects of cashew nut shell liquid feeding on methanogen behaviour in the rumen. *Microbial Biotechnology*, *14*(1), 277–290. https://doi.org/10.1111/1751-7915.13702

Martius, C., Wassmann, R., Guérin, L., Pham, T. T., Pingault, N., Tran, N., Mwambo, F., & Chin Yee, C. (2023). *Food systems emissions in Vietnam and their reduction potential: A country profile*. Center for International Forestry Research (CIFOR); and World Agroforestry (ICRAF). https://doi.org/https://doi.org/10.17528/cifor-icraf/009048

Marui, J., Shompoosang, S., & Panthavee, W. (2020). pH-dependent liquefaction of Thai rermented rice noodles (khanom jeen) associated with bacterial amylolytic enzymes. *Japan Agricultural Research Quarterly*, *50*(1), 41–45. https://doi.org/https://doi.org/10.1007/s12529-013-9337-7

Mgaya, J., Shombe, G. B., Masikane, S. C., Mlowe, S., Mubofu, E. B., & Revaprasadu, N. (2019). Cashew nut shell: a potential bio-resource for the production of bio-sourced chemicals, materials and fuels. *Green Chemistry*, *21*(6), 1186–1201. https://doi.org/10.1039/C8GC02972E

Ministry of Agriculture and Cooperative of Thailand. (2015). *Database of food consumption of Thai people 2013-2015*. http://consumption.acfs.go.th/main#

Ministry of Agriculture and Rural Development and Ministry of Science and Technology Vietnam. (2018). *TCVN 12380:2018 Raw cashew nut technical requirements*. https://vinacas.com.vn/uploads/download/tieu-chuan-hat-dieu-tho-tcvn-12380-2018-vietnam-8217-s-rcn-standards-2018-1639637521-vbqnt.pdf

Ministry of Natural Resources and Environment of Thailand. (2024). *Thailand's first biennial transparency report*. https://www.undp.org/thailand/publications/Thailand-First-Biennial-Transparency-Report-BTR1#:~:text=This%20report%2C%20the%20first%20BTR%2C%20contains%20updates%20of,support%20received%2C%20prepared%20in%20accordance%20with%20the%20MPGs.

Nguyen, V. T., Maeda, K., Nishimura, Y., Nguyen, T. T. H., La, K. Van, Nguyen, D. D., & Suzuki, T. (2022). Emission factors for Vietnamese beef cattle manure sun-drying and the effects of drying on manure microbial community. *PLOS ONE*, *17*(3), e0264228. https://doi.org/10.1371/journal.pone.0264228

Office of Agricultural Economics of Thailand. (2024).

Shinkai, T., Enishi, O., Mitsumori, M., Higuchi, K., Kobayashi, Y., Takenaka, A., Nagashima, K., Mochizuki, M., & Kobayashi, Y. (2012). Mitigation of methane production from cattle by feeding cashew nut shell liquid. *Journal of Dairy Science*, *95*(9), 5308–5316. https://doi.org/https://doi.org/10.3168/jds.2012-5554

Tee, T. P., Goh, Y. M., Zainudin, M. H. M., Candyrine, S. C. L., Sommart, K., Kongphitee, K., Sumamal, W., Phaowphaisal, I., Namsilee, R., Angthong, W., Sunato, S., Keaokliang, O., Maeda, K., Thu, N. V., Trung, T. T., Dong, N. T. K., Purnomoadi, A., Kurihara, M., Jayanegara, A., … Liang, J. B. (2022). Enteric methane emission models for diverse beef cattle feeding systems in South-east Asia: A meta-analysis. *Animal Feed Science and Technology*, *294*, 115474. https://doi.org/10.1016/j.anifeedsci.2022.115474

Thailand Taxonomy Board. (2025). *Thailand Taxonomy: Agricultural Sector.* https://www.bot.or.th/content/dam/bot/financial-innovation/sustainable-finance/green/taxonomy/03_EN_Thailand_Taxonomy-Agriculture_Sector.pdf

The Intergovernmental Panel on Climate Change (IPCC). (2006). *2006 IPCC Guidelines for national Greenhouse gas inventories*. https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

Tubiello, F. N. (2018). Greenhouse gas emissions due to agriculture. In Encyclopedia of Food Security and Sustainability (pp. 196–205). Elsevier. https://doi.org/10.1016/B978-0-08-100596-5.21996-3

Supplemental Table 1. Correspondence of emission categories between the agricultural sectors of IPCC and FAO

IPCC	FAO	Gases
Cultivation of histosols	Drained organic soils	N_2O
Inorganic N fertilizer	Synthetic fertilizers	N_2O
Crop residues	Crop residues	N_2O
Manure deposited on pasture, range, and paddock	Manure left on pasture	N_2O
Manure applied to soils	Manure applied to soils	N_2O
Manure management	Manure management	CH_4; N_2O
Enteric fermentation	Enteric fermentation	CH_4
Prescribed burning of savanna	Savanna fires	CH_4; N_2O
Burning crop residues	Burning - crop residues	CH_4; N_2O
Rice cultivation	Rice cultivation	CH_4

Source: FAO (2023). FAOSTAT domain emissions totals. *Methodological note,* release October 2023.

ISBN: 978-4-906635-28-3

Japan International Research Center for Agricultural Sciences (JIRCAS)
1-1 Ohwashi, Tsukuba, Ibaraki 305-8686, Japan
Tel: +81-29-838-6313 Fax: +81-29-838-6316

https://www.jircas.go.jp/en/greenasia/report